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Narragansett Bay 3VS Report
Model Summary for Peer Review

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Prepared for:

U.S. Environmental Protection Agency

Office of Research and Development

Region 1

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ABBREVIATIONS USED IN THIS REPORT

3VS	Triple Value Simulation
BAU	Business as Usual (i.e., baseline scenario runs in the model)
BEA	Bureau of Economic Analysis
BMP	Best Management Practices
Chl A	Chlorophyll A
CHRP	Coastal Hypoxia Research Program
CMAQ	Community Multi-scale Air Quality model
CSO	Combined Sewer Overflow
EPA (or USEPA)	Environmental Protection Agency Office of Research and Development
GDP	Gross Domestic Product
ICLUS	Integrated Climate and Land Use Scenarios
ISDS/OWTS	Independent sewage disposal systems or onsite wastewater treatment systems
LID/GI	Low-impact development and green infrastructure
LRT	Local Residence Time
MA	Massachusetts
MassDEP	Massachusetts Department of Environmental Protection
N	Nitrogen
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
O&M	Operations and Management
P	Phosphorus
RI	Rhode Island
RIDEM	Rhode Island Department of Environmental Management
SPARROW	SPAtially Referenced Regressions On Watershed attributes model
STICS	Spatial Trends in Coastal Socioeconomics
T21	Threshold 21 Model
TMDL	Total Maximum Daily Load
UBWPAD	Upper Blackstone Water Pollution Abatement District
VHP	A model developed by Vadeboncoeur, Hamburg, and Pryor
WWTF	Wastewater treatment facilities

SECTION 1 | INTRODUCTION

1-1. PROBLEM DEFINITION AND BACKGROUND

The purpose of the Narragansett Triple Value Simulation (3VS) project is to promote the discovery and implementation of innovative approaches to nutrient reduction in New England. More specifically, the project aims to apply an innovative system dynamics approach to addressing the problem of nutrient pollution in the Narragansett Bay watershed. The goal of the project is to develop an integrated assessment model that can help policymakers identify sustainable solutions to avoid, reduce, or manage the negative effects of nitrogen pollution.

Nutrient pollution threatens the environmental and economic viability of our nation's waters. It can cause algal blooms that deplete oxygen needed for fish and shellfish survival, smother vegetation, discolor and foul water, and produce toxins that are harmful to both humans and animals. The two main nutrients that affect coastal waters are nitrogen and phosphorus. In Narragansett Bay, as in many coastal water bodies, the environmental impacts of nutrient pollution – primarily in the form of nitrogen – threaten a variety of social and economic activities, including recreational and commercial fishing, swimming, and tourism. Since nutrient pollution comes from a variety of sources and has a wide range of impacts, it is useful to understand the intricate linkages between the watershed's economic, social, and environmental systems.

EPA's Office of Research and Development (ORD) and Region 1 have identified nutrient pollution in coastal waters as a high-priority area in need of further research and urgent action. They selected the Narragansett Bay watershed to pilot a systems-focused approach to addressing nutrient pollution, due to the ecological, economic, and recreational importance of the bay to local stakeholders and the persistence of nutrient-related problems despite significant investments in water quality improvements. To develop this pilot model, EPA ORD formed a project team composed of representatives of EPA Region 1, Industrial Economics, Inc. (IEc) and KnowlEdge Srl. Throughout the model development process, the project team sought input from a large number of regional stakeholders, including Federal, state, and local government, local and regional academic and research institutions, private sector representatives (e.g., operators of wastewater treatment facilities), and non-governmental organizations. A summary of two stakeholder meetings conducted early in the model development process – including notes and attendance lists from each meeting – is included as Appendix B.

The model developed for the Narragansett Bay watershed uses a "triple value simulation" approach, an innovative framework that captures the dynamic interrelationships between economic, environmental, and social systems. This approach was first piloted in the Narragansett Bay watershed and then implemented in other areas, including Cape Cod, Massachusetts; Durham, North Carolina; and the Delmarva peninsula in Delaware, Maryland, and Virginia. The Narragansett 3VS model is a policy simulation tool, based on an integrated assessment methodology called "system dynamics," that draws from watershed-specific data and extensive stakeholder input. The model uses the Vensim modeling software (Ventana Systems, Inc. 2011) and includes a user-friendly, dashboard-style visualization interface that enables users to explore different scenarios and interpret results in order to evaluate alternative policies and interventions aimed at reducing adverse nutrient impacts to the watershed.

The Phase I version of the Narragansett 3VS model was completed in March 2012 and the Phase II version was completed in September 2013. Additional revisions were made to the model in response to feedback from stakeholders, resulting in the final version that is being submitted for peer review.

1-2. PROJECT DESCRIPTION

In Phase I of this project, the project team developed an initial prototype of the Narragansett 3VS model intended to provide a systems-level understanding of the nitrogen issue in the bay and facilitate exploration of an integrated strategy for addressing this issue through cost-effective, sustainable policy options. The model was developed using existing data from a variety of sources, including Federal, state, and local governments, NGOs, and academic experts. In addition, the team used models previously developed by researchers studying the bay and consulted with their developers to ensure that the data from these models were appropriate for application in the Narragansett 3VS model. The Narragansett 3VS model differs in scope and purpose from other models previously developed for the bay; rather than modeling nutrient pollution in the bay exclusively, the Narragansett 3VS model aims to incorporate the social and economic impacts throughout the watershed that result from nitrogen pollution.

Phase II of the project involved further refinement of the model and the incorporation of additional environmental, economic and societal indicators and relationships, as well as disaggregating the bay into 14 separate regions, or "boxes." As in Phase I, we relied solely on secondary data in the modeling effort. Research and data collection activities included identifying, compiling, evaluating, and synthesizing literature and data on the following topics:

- Subsystems, resource flows, and issues of concern related to nutrient pollution in the Narragansett Bay watershed;
- Current and potential nutrient reduction initiatives in the bay by EPA and other entities;
- Relevant social, environmental, and economic data specific to the watershed.

1-3. STRUCTURE OF THIS REPORT

This report presents an overview of the Narragansett 3VS model. It is intended to serve as a reference to advanced users and/or reviewers of the model. It is organized in three sections:

- **Section 2, Model Description**: This section provides an overview of the Narragansett 3VS model, describing the data sources used to develop the model and illustrating the relationships that serve as primary drivers of change in the system that the model aims to represent.
- **Section 3, Model Outputs**: This section presents the results of several potential policy scenarios designed based on input from stakeholders in the Rhode Island Department of Environmental Management (RIDEM). The scenarios and selected model outputs are meant to be illustrative of how the model can be used to evaluate alternative policy interventions.
- **Section 4, Quality Assurance**: This section provides a detailed evaluation of the quality of the model, including assessing the data used to develop the model, the relationships that form the model's structure, and the behavior generated by the model.

Separate lists of references are included in each of these three sections. This report also includes three appendices:

- Appendix A provides the output of the model's "units error" function;
- Appendix B provides a summary of two stakeholder outreach meetings; and
- Appendix C (provided as a separate HTML document) summarizes the results of a comprehensive documentation of the model.

SECTION 2 | MODEL DESCRIPTION

2-1. INTRODUCTION

This section provides an overview of the data sources and relationships used to develop the Narragansett 3VS model. It is meant to provide the reader with a thorough understanding of what is included in the model and how the model was developed. More detailed documentation of the model can be found in Appendix C, "SDM Documentation of the Narragansett 3VS Model," which is provided as a separate HTML document.

Exhibit 2-1 presents a schematic that uses the triple-value framework of economy, society, and environment to illustrate the primary variables included in the Narragansett 3VS model, as well as key relationships among them. The exhibit presents all of the important elements of the system that the model represents, including both variables and relationships included in the model (solid lines) as well as those that could not be included in the model (dashed lines) due to a lack of data on how to reflect them.[1] Black lines indicate amplifying causal relationships while red lines indicate diminishing causal relationships. Interventions are represented by green circles and situated on the targeted causal relationship.

The main elements of the schematic can be grouped into loadings (boxes with arrows pointing toward the grey box labeled "Flows of water, nutrients, pathogens via land, groundwater, surface water"), environmental relationships (boxes in the "Environment" section of the schematic), and impacts on economy and society (all other boxes).

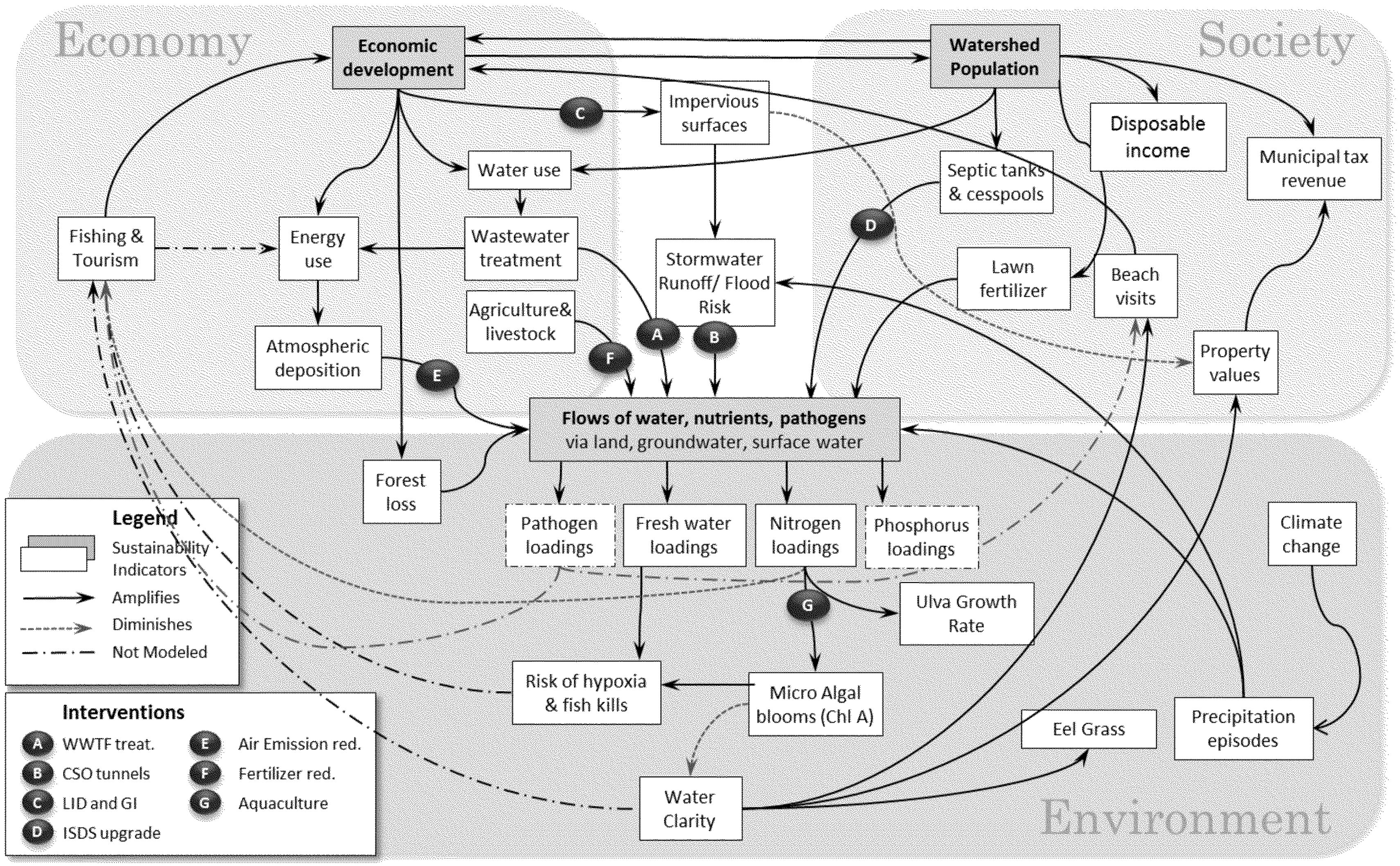
This section is divided into subsections covering the following topics:

- 2-2. The general structure of the model, including the "dashboard" user interface.
- 2-3. The geographic scope of the model, specifically how the model divides the Narragansett Bay watershed into eight subwatershed areas and divides the bay into 14 regions;
- 2-4. The indicators included in the model, as well as those indicators that were considered for the model but ultimately not included;
- 2-5. How the model uses components of another model designed to assess sustainable development strategies, Threshold 21;
- 2-6. How the model estimates nitrogen loadings dynamically from several different sources;
- 2-7. How the model simulates the flow of nitrogen within Narragansett Bay, which affects how the environmental impacts of nitrogen pollution are distributed spatially across the bay;
- 2-8. How the model simulates the implementation of selected policy interventions;
- 2-9. The relationships used to model the environmental, economic, and social impacts of nitrogen loadings to Narragansett Bay; and

[1] For further information about why certain variables and relationships were not included in the model, see Exhibit 2-4.

2-10. Additional research conducted during the development of the Narragansett 3VS model, including data sources that we used to develop the model, other models that indirectly guided the development of the model, data sources that could contribute to future versions of the model, and data sources that were determined not to fit the scale and scope of this model.

EXHIBIT 2-1. SCHEMATIC OF ECONOMIC, SOCIAL, AND ENVIRONMENTAL VARIABLES AND RELATIONSHIPS IN THE NARRAGANSETT 3VS MODEL

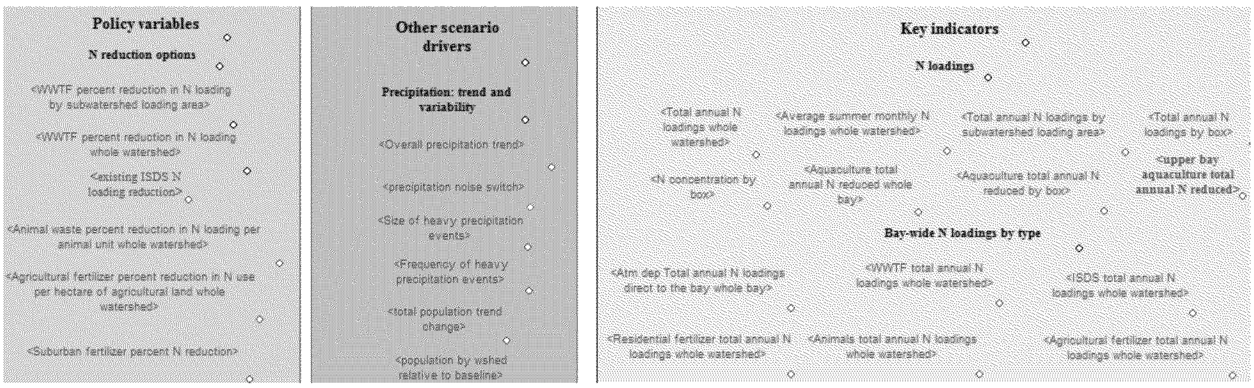


EPA-R1-2018-000110_0000618

2-2. MODEL STRUCTURE AND USER INTERFACE

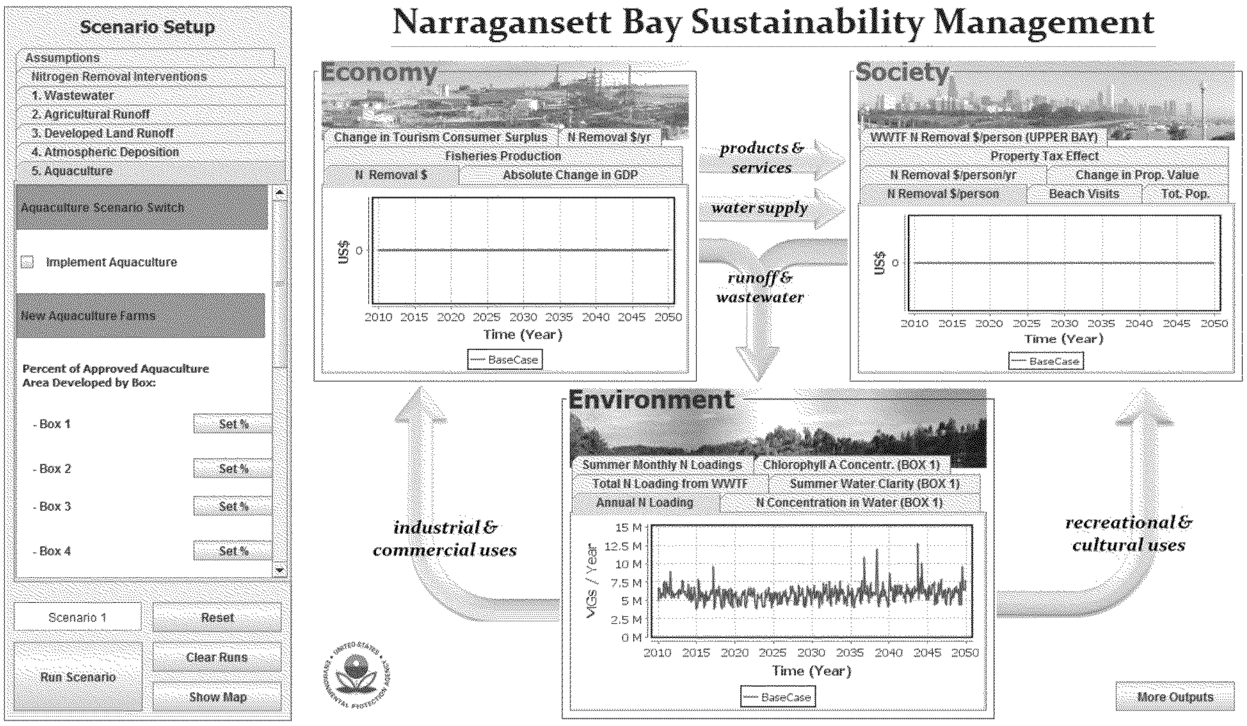
The Narragansett 3VS model is built using Vensim software and is organized in 27 views. Each view represents a different component of the system modeled (e.g., population, nitrogen loadings from wastewater, environmental impacts of nitrogen), but the variables in each view interact with variables in all other views. Views 1-12 were largely drawn from the Threshold 21 model (described in greater detail in Section 2-5), while the remaining views were developed specifically for the Narragansett Bay model. View 27 features a "dashboard" interface that allows users to define policy scenarios, adjust selected model assumptions, and access most of the social, economic, and environmental indicators that the model features. Exhibit 2-2 presents a snapshot of this dashboard view. The dashboard only reproduces some of the variables located elsewhere in the model. Users interested in modifying the model can adjust values of variables, regardless of whether they are included in the dashboard.

EXHIBIT 2-2. SELECTION OF THE DASHBOARD INTERFACE FOR THE NARRAGANSETT 3VS MODEL



In addition to the dashboard interface, the Narragansett 3VS model also includes a separate user interface program that allows users to define policy scenarios, adjust selected model assumptions, and view graphs that show the behavior of selected indicators over time. The main view of this user interface program is presented in Exhibit 2-3. It should be noted that – unlike the full model in Vensim – the user interface restricts which variables the user can view or modify. In addition, the Vensim version of the model allows users to export model outputs for further analysis in other programs, while the user interface version does not.

EXHIBIT 2-3. NARRAGANSETT 3VS USER INTERFACE MAIN VIEW



2-3. GEOGRAPHIC SCOPE

The Narragansett 3VS model examines the impact of nitrogen pollution on Narragansett Bay, and the human and environmental systems related to it. Though the model is not spatially explicit, it does have a spatial component in that it considers contributions to nitrogen pollution from different areas of the Narragansett Bay watershed as well as the economic, social, and environmental impacts of nitrogen pollution on different regions of Narragansett Bay. The divisions that the model uses for both the Narragansett Bay watershed and the bay itself are illustrated in Exhibit 2-4. This section discusses how the model divides the Narragansett Bay watershed into eight "subwatershed loading areas" and divides Narragansett Bay into 14 "bay boxes" or regions.

SUBWATERSHED LOADING AREAS

In order to show how nitrogen loadings and other variables that affect loadings vary by region of the Narragansett Bay watershed, we divided the watershed into eight areas that we refer to as "subwatershed loading areas" (hereafter "subwatershed areas"). We based this division on a model developed by Vadeboncoeur, Hamburg, and Pryor (discussed in greater detail below), which defined areas by municipal boundaries that roughly correspond to subwatersheds (or groupings of subwatersheds) within the overall Narragansett Bay watershed. These regions, which are labeled in Exhibit 2-4, are:

1) Blackstone Above Millville (MA only)
2) Blackstone Above Manville (RI only)
3) Small Watersheds (both MA and RI)
4) Mid/Lower Taunton (MA only)

5) Taunton above Bridgewater (MA only)
6) Upper Bay (both MA and RI)
7) Pawtuxet (RI only)
8) Lower Bay (both MA and RI)

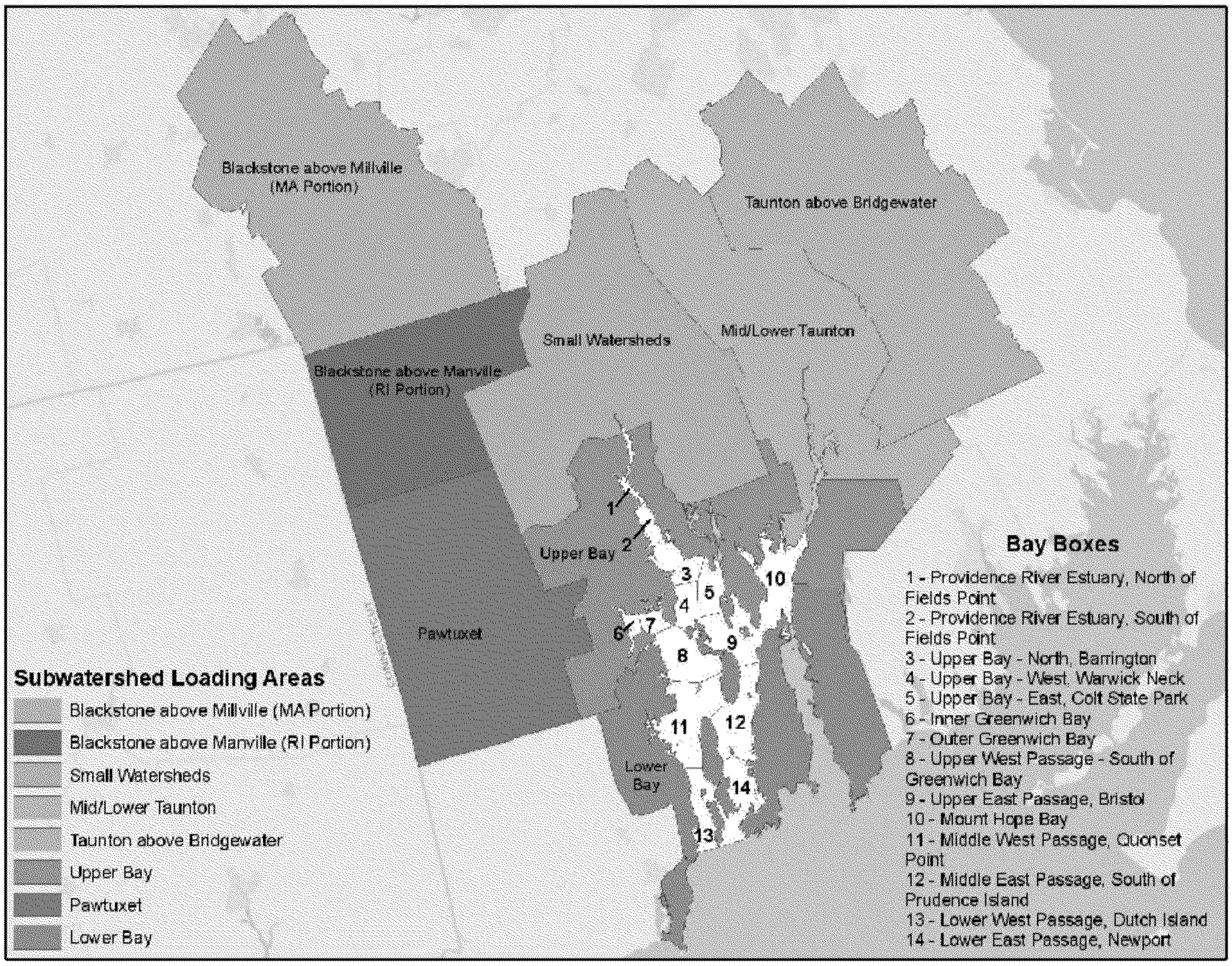
BAY BOXES

Just as the factors that drive nitrogen pollution are not distributed evenly across the Narragansett Bay watershed, the impacts of nitrogen pollution are not distributed evenly across Narragansett Bay itself. Accordingly, the 3VS model divides the bay into 14 bay "boxes," or regions. This division of the bay is based on the EcoGEM model (discussed in greater detail below), which divides the bay into 15 segments, or "boxes." The 3VS model focuses on 14 of these boxes, excluding the Sakkonet river, which is generally viewed as hydrologically distinct from Narragansett Bay. The EcoGEM model simply labels these boxes by number, but we have assigned them the following names:

1) Providence River Estuary, North of Fields Point
2) Providence River Estuary, South of Fields Point
3) Upper Bay North (Barrington)
4) Upper Bay West (Warwick Neck)
5) Upper Bay East (Colt State Park)
6) Inner Greenwich Bay
7) Outer Greenwich Bay
8) Upper West Passage (South of Greenwich Bay)
9) Upper East Passage (Bristol)
10) Mount Hope Bay
11) Middle West Passage (Quonset Point)
12) Middle East Passage (South of Prudence Island)
13) Lower West Passage (Dutch Island)
14) Lower East Passage (Newport)

The 14 bay boxes are also labeled in Exhibit 2-4. Note that due to a lack of sufficiently disaggregated loadings data, the 3VS model merges boxes 6 and 7, effectively treating the entirety of Greenwich Bay as a single segment.

EXHIBIT 2-4. SUBWATERSHED AREAS AND BAY BOXES USED IN THE NARRAGANSETT 3VS MODEL



2-4. SOCIAL, ECONOMIC, AND ENVIRONMENTAL INDICATORS

This section lists the key economic, social, and environmental indicators included in the Narragansett 3VS model. These indicators – including both quantitative and semi-qualitative indicators – are the outputs that the model generates to illustrate the impacts of different policy scenarios (including the baseline, "no further action" scenario) on the human and physical environment of the Narragansett Bay system. Exhibit 2-5 lists the indicators in the model, together with the unit for each indicator. Exhibit 2-6 lists indicators that were considered for inclusion, but ultimately not included in the model. We include this list to demonstrate the breadth of the interactions among the project team and stakeholders in exploring the potential scope of indicators to include in the model. The exhibit provides a brief summary of why each indicator was not included in the current version of the model; additional information on our research into these variables can be found in Section 2-10. As noted in that section, a number of these indicators may be added to future iterations of the model as more information and resources become available, or as the model is applied to additional locations.

EXHIBIT 2-5. INDICATORS INCLUDED IN THE MODEL QUANTITATIVELY

CATEGORY	INDICATOR	UNIT
Economic/Social	GDP (change relative to baseline)	US$
Economic/Social	Per Capita Disposable Income	US$
Economic/Social	Property Value: - Related to Water Clarity - Related to Proximity to Open Space (LID/GI Use Case only)	US$
Economic/Social	Municipal Tax Revenue (related to changes in property value)	US$
Economic/Social	Employment (related to aquaculture)	Jobs
Economic/Social	Commercial Fish Production (finfish landings: total value and change relative to baseline)	US$
Economic/Social	Energy Use (energy demand curve for different levels of nitrogen removal)	kWh
Economic/Social	Beach Visits	People
Economic/Social	Tourism Activity (consumer surplus from beach visits: change relative to baseline)	US$
Economic/Social	Total Direct Cost of Nitrogen Reductions: Includes costs of - Aquaculture (calculated as US$/farm), - Independent sewage disposal system (ISDS) Improvements (US$/unit upgraded) - Wastewater treatment facility (WWTF) Reductions (US$ for operations and maintenance and annualized capital cost/kg N reduced) - Subwatershed area-scale low-impact development and green infrastructure (LID/GI) retrofits (US$/acre of impervious cover reduced below initial levels) - Residential and Agricultural Fertilizer reductions (US$/kg N reduced), and - Animal Waste Reductions (US$/kg N reduced).	US$
Economic/Social	Aquaculture Revenue	US$
Environmental	Annual and Monthly Nitrogen Loadings, by Box (area of the bay), subwatershed area, and source type: - WWTFs - ISDSs - Residential and agricultural fertilizer - Animal waste - Atmospheric deposition (direct to the bay and via the watershed) - Surface Water Runoff from Developed Land	kg
Environmental	Nitrogen Concentration (by Box)	mg/L
Environmental	Micro Algal Blooms, represented by chlorophyll A (by Box)	µg /L
Environmental	Ulva Growth Rate (by Box)	Percent
Environmental	Hypoxia Risk (by Box, semi-qualitative scale - low, medium and high)	Unitless
Environmental	Water Clarity/Secchi Depth (by Box)	NTU
Environmental	Eel Grass Improvement Potential (by Box, semi-qualitative scale - low, medium and high)	Unitless
Environmental	Daily Precipitation (can be adjusted to reflect expected impacts of	ml

	climate change on precipitation event frequency and size)	

EXHIBIT 2-6. INDICATORS NOT MODELED

CATEGORY	INDICATOR	COMMENT
Economic/Social	Human Health	After interviewing contacts at the Rhode Island Department of Health and other experts, we found that pathogens (stored in seaweed and macroalgae) are the primary source of beach-related illness. Because pathogen loadings are not currently included in the Narragansett 3VS model, we do not model these health impacts. Additional health impacts are tied to air emissions (especially particulates). The current version of the Narragansett 3VS model includes reductions in N deposition from air emissions, but does not address the associated reductions in particulate concentrations.
Economic/Social	Aesthetics	We were not able to establish a relationship between nitrogen loadings and aesthetics; however, we do estimate the effects of nitrogen loading on water clarity, which in turn affects property value and beach visits.
Economic/Social	Access to Water	We were not able to establish a relationship between nitrogen loadings and access to water; however, we do model other indicators that relate to water access, such as beach visits.
Economic/Social	Human Well-Being	Stakeholders raised this as a potential indicator to include in the model. The project team determined that indicators of overall human well-being indicators were beyond the scope for the current model; however they could be addressed in future versions of the model or in applications of the model to other locations.
Economic/Social	Social Justice	Stakeholders raised this as a potential indicator to include in the model. The project team determined that social justice indicators were beyond the scope for the current model; however they could be addressed in future versions of the model or in applications of the model to other locations.
Economic/Social	Flood Risk	EPA has researched the effects of LID/GI on reducing flood risk. We explored the potential of incorporating regression data on the relationship of open space and flooding, but additional effort beyond the resources available for developing the current version of the model would be required to tie flood risk directly to imperviousness, which is the key parameter driven by the use of LID/GI.
Economic/Social	Recreational Fishing and Boating	We were not able to establish a relationship between nitrogen loadings and recreation and therefore do not model impacts on recreational fishing and boating. However, we do model the impact of nitrogen on commercial fish landings. It could be possible to model the impact of nitrogen on recreational fishing activity if we were to assume that the impact on recreational fishing is proportional to the impact on commercial fish landings.

Economic/Social	Tourism (beyond beach visits)	We were not able to establish an overall relationship between nitrogen loadings and tourism. Additionally, the quantitative, Bay-specific data on tourism that we identified are out of date so further research would be necessary to update these data.
Economic/Social	Shellfish Growth Rate	In developing the 3VS model, we explored including a relationship between nitrogen loadings and shellfish growth rate. However, the available data on this relationship did not appear to capture the full range of effects of nitrogen loading on growth rate. We therefore decided to exclude shellfish growth rates from the model, rather than presenting an incomplete picture of the impact of nitrogen on shellfish.
Economic/Social	Employment Impacts (beyond aquaculture)	A study ("A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia's Watersheds") estimated the employment benefits of implementing LID/GI in Philadelphia, but the study did not provide sufficient information to allow us to apply the approach to the Narragansett Bay watershed.[2] Further investigation of this indicator may be warranted for future versions of this model and applications of it to other locations.
Environmental	Greenhouse Gas Emissions	For this version of the model, we focused on indicators that would have a more immediate local impact, in order to better demonstrate the potential for feedback loops within the system.
Environmental	Metals Loading	We found data on the impact of specific LID/GI Best Management Practices (BMPs) on reducing metals loading, but no data on baseline metals loading or on environmental relationships between metals and other indicators.
Environmental	Phosphorus Loading	The model used to estimate nitrogen loadings entering Narragansett Bay from rivers also provides estimates of phosphorus loadings, but we did not identify data sources that would allow us to define relationships between phosphorus loadings and other variables in the model. In addition, because the primary focus of the Narragansett 3VS model is on the impact of nitrogen pollution in coastal waters, we did not research the environmental impacts of phosphorus pollution, which are primarily felt in freshwater environments.
Environmental	Pathogen Loading	We recognize that pathogens affect human health by contributing to beach closures and advisories, but we were not able to find sufficient data for pathogen loadings or for describing relationships between pathogens and other variables in the model.
Environmental	Sediment Loading	We found data on the impact of specific LID/GI BMPs on reducing sediment loading, but no data on baseline sediment loading or on environmental relationships between sediment and other indicators.
Environmental	Groundwater recharge	Stakeholders raised this as a potential indicator to include in the model. The project team determined that groundwater recharge was beyond the scope for the current model; however it could be addressed in future versions of the model or in applications of the model to other locations.

[2] Raucher, R., and Clements, J. 2010. "A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia's Watersheds." *WEFTEC*. New Orleans, LA.

Environmental	Dissolved Oxygen	A quantitative dissolved oxygen metric is beyond the scope of the bio-physical realism of the 3VS model. The primary interest in dissolved oxygen is as a measure of hypoxia. The model incorporates a qualitative summer hypoxia metric based on changes in the hypoxia risk factors of precipitation, bay location, and nitrogen concentration.

2-5. THRESHOLD 21 MODEL

The Narragansett 3VS model was originally designed to be a customized version of the Threshold 21 (T21) model developed by the Millennium Institute (MI). The T21 model is a dynamic scenario analysis tool designed to support development of a comprehensive, integrated, and long-term roadmap for sustainable development. It has been widely adapted to examine the cross-sector impacts of policy alternatives in multiple settings throughout the world, including serving as the underpinnings of the UNEP Green Economy Report. The full T21 model framework includes more than one thousand equations, 60 stock variables, and several thousand feedback loops, grouped into 18 sectors (six social sectors, six economic sectors, and six environmental sectors). Additional information on the T21 model can be found at http://www.millennium-institute.org/integrated_planning/tools/T21/. For the Narragansett 3VS model, we started with a selection of sectors from the T21 model and then added sectors specifically developed for the analysis of nitrogen loadings in the bay (e.g., sources of nitrogen loadings, environmental impacts of nitrogen loadings, and social and economic impacts of increased nitrogen concentrations in the bay).[3] The remainder of the report focuses exclusively on these additional sectors.

2-6. NITROGEN LOADINGS

To represent the problem of nitrogen pollution in Narragansett Bay, we designed the nitrogen loadings module in the Narragansett 3VS model to accomplish the following goals:

1. Estimate nitrogen loadings dynamically, using other variables estimated endogenously within the model.
2. Where possible, calibrate estimated nitrogen loadings to match observed data on nitrogen loadings in Narragansett Bay.
3. Disaggregate loadings by source category, by region (or "box") of the bay, and by season.

In accomplishing these goals, we relied primarily on two previously developed models of nitrogen loadings to Narragansett Bay and supplemented those models with site-specific and updated data sources, wherever possible. Exhibit 2-7 summarizes our estimates of total nitrogen loadings by source category for the 14 bay boxes, showing estimated annual loadings in 2002. Note that these estimates were used to calibrate the model, but because the model estimates loadings dynamically, these estimates do not precisely match the estimates generated by the model itself. A detailed comparison between the model's estimates and the estimates used for calibration purposes can be found in Section 4. The remainder of this section presents our approach for estimating Narragansett Bay nitrogen loadings with the Narragansett 3VS model. We first describe the two previously developed nitrogen loadings models that served as the

[3] The sectors in the Narragansett 3VS model taken from the T21 model framework are: "Population," "Economy-GDP," "Agriculture," "Animals," "Industry," "Services," "Households," "Government," "Land Use," "Water Demand," and "Energy Consumption." For the majority of scenarios that the 3VS model is designed to assess, there is little to no variation in the behavior of the variables included in these sectors.

foundation for this effort, then provide additional detail on each source category, and finally summarize the disaggregation of total loadings by bay box and by season.

MODELS OF NITROGEN LOADINGS

We used two models to develop the nitrogen loadings module within the Narragansett 3VS model:

1. A model of historical nitrogen loadings to Narragansett Bay, developed by Vadeboncoeur, Hamburg, and Prior (hereafter "VHP model").[4]
2. The New England version of the SPARROW (SPAtially Referenced Regressions On Watershed attributes) model, developed by USGS (hereafter "SPARROW").[5]

This section summarizes how we used these two models to link nitrogen loadings to other variables in the model, calibrate nitrogen loadings to match observed data, and distribute loadings among the 14 boxes of Narragansett Bay.

Vadeboncoeur, Hamburg, and Pryor (VHP) Model

The VHP model was developed for a study published in 2010 that estimated historic trends in nitrogen loadings to Narragansett Bay. This model uses literature-derived loading coefficients to estimate nitrogen loadings by source category from a set of independent variables, including sewered and non-sewered populations, atmospheric deposition, land cover (i.e., forested, agricultural, or developed), and fertilizer usage. The 2010 study found that historic nitrogen loadings estimated by the VHP model corresponded closely to observed values, both for the Narragansett Bay watershed as a whole and for the Pawtuxet, Blackstone, and Taunton subwatershed areas.

For several source categories, we used the loading coefficients from the VHP model to relate nitrogen loadings by source category to other variables calculated endogenously within the model. This method allowed us to estimate nitrogen loadings dynamically in the model. That is, as key variables in the model (e.g., population, land use, air emissions) change over time or in response to policy interventions, nitrogen loadings to Narragansett Bay change accordingly. Exhibit 2-8 lists the source categories used in the VHP model, together with the variables used to derive loadings from each source, as well as the model's estimated nitrogen loadings for 2000.

[4] Vadeboncoeur, A., Hamburg, S.P., and Pryor, D. 2010. "Modeled Nitrogen Loading to Narragansett Bay: 1850 to 2015." Estuaries and Coasts. 33:1113-1127.

[5] USGS. 2011. SPARROW Surface Water-Quality Modeling. Available at: http://water.usgs.gov/nawqa/sparrow/.

EXHIBIT 2-7. SUMMARY OF ESTIMATED NITROGEN LOADINGS TO NARRAGANSETT BAY BY BAY BOX, 2002 (KG)

BAY BOX	WASTEWATER			SURFACE WATER RUNOFF						ATM DEP DIRECT TO THE BAY	TOTAL
	WWTF		ISDS	UNDEVELOPED LAND			DEVELOPED LAND				
	UPSHED WWTF	BAYSIDE WWTF		ATM DEPOSITION	AGRICULTURAL FERTILIZER	ANIMALS	ATM DEPOSITION	RESIDENTIAL FERTILIZER	OTHER STORMWATER		
1	1,000,000	1,300,000	340,000	130,000	69,000	19,000	68,000	98,000	65,000	6,900	3,100,000
2	320,000	0	140,000	52,000	16,000	5,100	23,000	40,000	27,000	9,200	630,000
3	0	0	370	490	320	90	3,200	7,900	5,200	21,000	38,000
4	0	0	140	0	0	0	0	2,600	1,700	14,000	18,000
5	34,000	0	12,000	13,000	21,000	4,000	6,000	22,000	15,000	18,000	140,000
6	0	13,000	5,900	880	490	76	3,100	7,400	4,900	6,000	42,000
7	0	0	5,900	150	23	5	520	9,700	6,400	8,600	31,000
8	0	0	45,000	4,200	1,800	240	3,000	17,000	11,000	31,000	110,000
9	0	96,000	1,300	330	220	53	500	7,100	4,700	32,000	140,000
10	700,000	440,000	180,000	98,000	120,000	17,000	47,000	100,000	67,000	47,000	1,800,000
11	0	12,000	21,000	2,400	2,500	220	1,800	5,600	3,700	38,000	87,000
12	0	0	2,200	850	2,600	620	1,200	5,000	3,300	29,000	45,000
13	0	0	24,000	480	360	88	330	15,000	9,900	13,000	63,000
14	0	180,000	1,100	91	0	0	180	2,900	1,900	17,000	210,000
Total	2,100,000	2,100,000	770,000	300,000	240,000	46,000	160,000	340,000	230,000	290,000	6,500,000
Note: Values may not sum to totals due to rounding.											

EXHIBIT 2-8. SOURCE CATEGORIES AND INDEPENDENT VARIABLES USED TO CALCULATE NITROGEN LOADINGS IN THE VADEBONCOEUR, HAMBURG, AND PRYOR MODEL

SOURCE CATEGORY	INDEPENDENT VARIABLE(S)	ESTIMATED LOADINGS IN 2000 (KG)
Wastewater from Treatment Facilities	Sewered population	4,000,000
Wastewater from Independent Sewage Disposal Systems (ISDS)	Non-sewered population	1,100,000
Runoff from Animal Waste	Animal stock	200,000
Runoff from Agricultural and Suburban Fertilizer	Fertilizer application per hectare	1,000,000
Runoff from Atmospheric Deposition on the Watershed	Total N deposition per hectare; land use distribution (forest/agricultural/developed)	1,300,000
Atmospheric Deposition Direct to the Bay	Total N deposition per hectare	280,000
Total		**8,000,000**
Note: Values may not sum to total due to rounding. Source: VHP Model Data (Vadeboncoeur et al., 2010)		

For 2000, the VHP model estimates that total nitrogen loadings to Narragansett Bay from these six source categories were 8.0 million kg (as a best estimate, with a range between 4.3 million and 12.7 million kg).

New England SPARROW Model

SPARROW is a regression-based model that estimates nitrogen loadings by source category, calibrated so that total estimated nitrogen loadings match observed nitrogen fluxes through river networks. Because SPARROW estimates nitrogen loadings for each river flowing into the bay, it provides us with a means of estimating total loadings separately by bay box. SPARROW disaggregates total nitrogen loadings among five source categories, as summarized in Exhibit 2-9.

EXHIBIT 2-9. CATEGORIES OF NITROGEN LOADINGS SOURCES IN THE NEW ENGLAND SPARROW MODEL AND ESTIMATES OF 2002 LOADINGS TO NARRAGANSETT BAY

SOURCE CATEGORY	SPARROW CATEGORY	ESTIMATED LOADINGS IN 2002 (KG)
Wastewater from Treatment Facilities (excluding those discharging directly to the bay)	Sewered Population	1,900,000
Runoff from Animal Waste	Manure	49,000
Runoff from Agricultural Fertilizer	Corn, Soy, and Alfalfa Fertilizer + Other Fertilizer	250,000
Runoff from Atmospheric Deposition on the Watershed (excluding developed land)	Atmospheric Deposition via Watershed	470,000
Runoff from Developed Land	Developed Land	1,400,000
Total		**4,100,000**
Note: Values may not sum to total due to rounding Source: SPARROW Model data (Milstead 2012)		

SPARROW estimates that total nitrogen loadings from these five source categories were 4.1 million kg in 2002. Notably, the SPARROW loading source categories differ from the VHP categories – SPARROW includes surface water runoff from developed lands but does not include unsewered population or atmospheric deposition direct to the bay. In addition, because SPARROW is calibrated to equal total nitrogen flux from rivers, it does not capture nitrogen loadings from sources that discharge directly to the bay, including several of the largest wastewater treatment facilities (WWTFs) in the watershed. Finally, SPARROW provides data on nitrogen loadings to Narragansett Bay for only 2002, making it useful for calibration purposes, but limiting its ability to help model nitrogen loadings dynamically.

The following sections discuss in greater detail how we used the VHP and SPARROW models, together with other data sources, to dynamically model nitrogen loadings to Narragansett Bay.

NITROGEN LOADINGS BY SOURCE CATEGORY

This section discusses how the nitrogen loadings module estimates loadings dynamically for nine different source categories, which can be grouped into the following three broad categories:

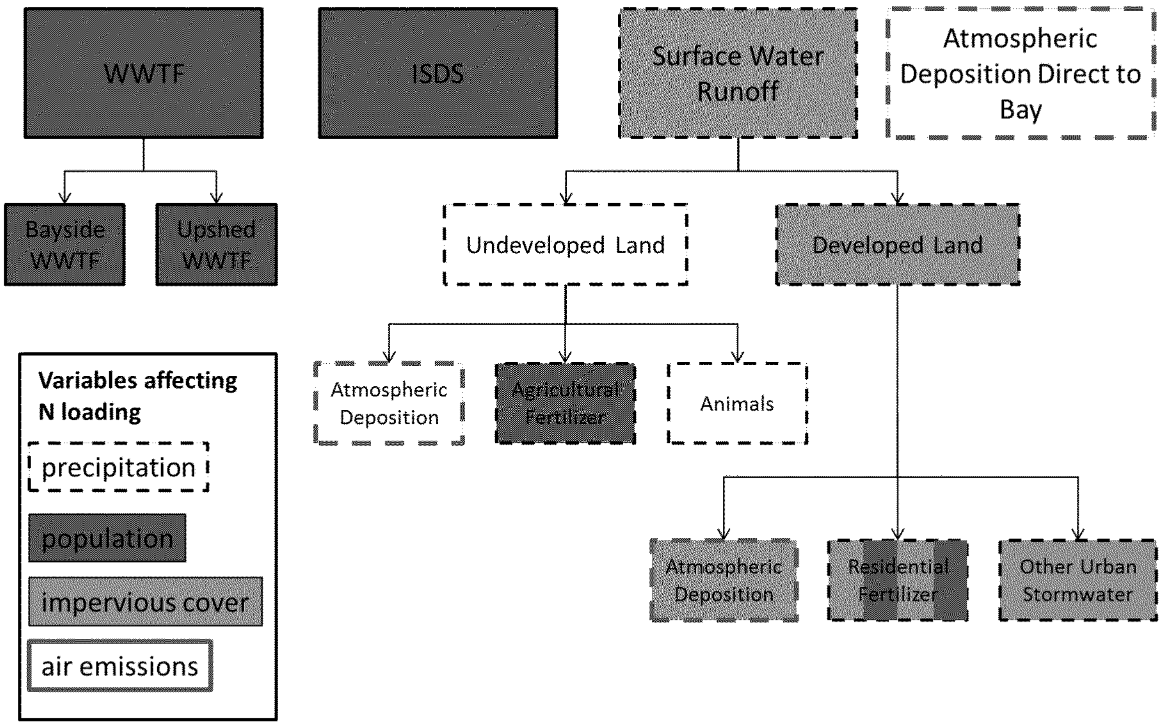
1. Nitrogen from wastewater, including from (1) wastewater treatment facilities (WWTFs) and (2) independent sewage disposal systems (ISDSs);
2. Nitrogen from surface water runoff, including from (3) animal waste, (4) agricultural and (5) residential fertilizer, atmospheric deposition on the watershed – both on (6) undeveloped and (7) developed land, and (8) other sources of urban runoff; and
3. Nitrogen from (9) atmospheric deposition direct to the bay.

Exhibit 2-10 summarizes the source categories used in the model. As the exhibit shows, the primary variables in the model affecting nitrogen loadings are precipitation, population, impervious cover, and air emissions of nitrogen. In the remainder of this section, we describe how we developed parameters in the model to dynamically estimate nitrogen loadings as a function of these and other variables. We also discuss how we calibrated the model using data from SPARROW, the VHP model, and other sources.

Wastewater Treatment Facilities (WWTFs)

A total of 31 WWTFs discharge wastewater that ends up in Narragansett Bay, including 15 facilities in the Rhode Island portion of the watershed and 16 facilities in the Massachusetts portion. To estimate nitrogen loadings from these facilities, we obtained facility-specific compliance and enforcement monitoring data for both MA and RI for the years 2000-2010. These datasets, which include average monthly effluent nitrogen concentrations and flow for all facilities in the Narragansett Bay watershed, allowed us to calculate more recent estimates of nitrogen loadings from wastewater from the sewered population than were available in either the VHP model or SPARROW. In addition, we used the monthly effluent data to disaggregate annual WWTF loadings by season, thereby capturing the effects of regulations limiting summer nitrogen concentrations. The model groups WWTF loadings into "bayside" (i.e., those that discharge directly into Narragansett Bay) and "upshed" (i.e., those that discharge into rivers that flow into the bay), in order to facilitate comparison to SPARROW's estimate of loadings for this category. SPARROW's estimate of WWTF loadings in 2002, which includes only upshed facilities, is 1.9 million kg; based on the compliance and enforcement monitoring data, the Narragansett 3VS model estimates 2002 loadings of 2.1 million kg for the same facilities.

EXHIBIT 2-10. FACTORS INFLUENCING NITROGEN LOADINGS IN THE NARRAGANSETT 3VS MODEL



In order to estimate WWTF loadings dynamically in the model, we divided summer and winter loadings for each facility by the estimated population that the facility served, yielding facility-specific seasonal per-capita loading coefficients. These coefficients allow the model to project changes in nitrogen loadings based on population changes, assuming that treatment levels remain constant.

Finally, to capture the expected effects of agreed-upon upgrades to nitrogen removal treatment in several facilities, we set the per-capita loading coefficients for these facilities to be reduced to a level representing compliance with nitrogen effluent limits in the year when the facilities are expected to implement enhanced treatment.[6]

Data sources used for this source category include:

- Monthly WWTF loadings in MA, 2000-2010: EPA's compliance and enforcement monitoring data.
- Monthly WWTF loadings in RI, 2000-2010: RIDEM compliance and enforcement monitoring data.
- Effluent concentrations at selected RI facilities, both current and target limits: A. Liberti, 2010. CHRP/Managers Meeting Presentation. Rhode Island Department of Environmental

[6] Ten facilities are expected to come into attainment with nitrogen effluent limits in years after 2011, the last year for which compliance and monitoring data were available. These include four facilities with a limit of 8.0 mg total nitrogen per liter (mgTN/l) (Cranston, Warwick, West Warwick, and East Providence in Rhode Island), one facility with a limit of 6.0 mgTN/l (Upton in Massachusetts), five facilities with a limit of 5.0 mgTN/l (East Greenwich, Bucklin, Fields Point, and Warren in Rhode Island, and Attleboro in Massachusetts); and one facility with a limit of 3.0 mgTN/l (Woonsocket in Rhode Island).

Management. December 9. Updated information provided in A. Liberti, RIDEM, Personal communication. November 24, 2014.

- Effluent concentrations at selected MA facilities, target limits: D. Pincumbe, EPA Region 1, Personal communication. September 30, 2014.
- Population served, RI facilities: WWTF RIDEM Office of Water Resources listing of Wastewater Facilities and Contacts. Available at: http://www.dem.ri.gov/programs/benviron/water/permits/wtf/potwops.htm.
- Population served, MA facilities: EPA Clean Watersheds Needs Survey 2008 Data and Reports: Detailed listing of Wastewater Treatment Plants Flows and Population Receiving Treatments for State of Massachusetts. Available at http://iaspub.epa.gov/apex/cwns2008/f?p=115:1:0::NO::: (query Wastewater Treatment Plant Flows and Population Receiving Treatment for the state of Massachusetts).

Independent Sewage Disposal Systems (ISDS)

As noted above, the VHP model estimates nitrogen loadings for wastewater from the non-sewered population, but SPARROW does not.[7] From discussion with state stakeholders and EPA, we determined that the VHP model likely overestimates loadings from independent sewage disposal systems (ISDSs). Accordingly, we used the following process to estimate ISDS loadings, disaggregated by bay box:

1. We first used GIS software to map the sewer system infrastructure in the Narragansett Bay watershed. For Rhode Island, we obtained the most up-to-date infrastructure data available from RIDEM for all sewered areas in the watershed. For Massachusetts, we obtained infrastructure data from the City of Fall River and the City of Taunton; we were not able to obtain GIS data from the City of Somerset.
2. We then determined the number of people in the watershed using ISDSs that discharge into Narragansett Bay. We first mapped known buildings or structures in Rhode Island using 2012 E-911 data obtained from RIGIS. Next, we determined the number of these structures that a) fall outside of the areas with sewer system infrastructure, and b) are located on soils with high infiltration rates that are connected to the bay or that overlap rivers and streams leading to the bay. Using 2010 census data on the average population per structure in Rhode Island, we estimated the number of people in Rhode Island using ISDSs that discharge into the bay. Dividing that number by the population of Rhode Island yielded an estimate of the percent of the population using ISDSs that discharge to the bay.[8] We then multiplied this number by the population of the watershed to produce an estimate of the total non-sewered population with nitrogen loadings that reach the bay.
3. To estimate the amount of nitrogen that these systems contribute to the bay, we first use a baseline per-person nitrogen value of 4.4 kg/person/year from the VHP model. We then assume

[7] Because SPARROW is calibrated so that total estimated nitrogen loadings by source category equal total observed nitrogen flux in rivers, it is likely that it does capture nitrogen loadings from ISDSs, but it attributes them to a different source category (such as "Developed Land"). As will be seen later, our estimate of total loadings to Narragansett Bay (excluding bayside WWTFs and atmospheric deposition direct to the bay) is approximately equal to SPARROW's estimate, though we distribute total loadings among source categories differently.

[8] E-911 data were not available for Massachusetts, so we assume that the percentage of the population using ISDSs that discharge into the Narragansett Bay is constant across the watershed.

that ten percent of nitrogen from these systems is removed via attenuation during groundwater transport. Finally, we assume that typical systems do not remove any nitrogen, and systems installed after 2002 remove ten percent of nitrogen from wastewater, due to advancing treatment technology and regulations requiring replacement of outdated systems. The model first applies the ten percent removal of upgraded systems and then applies the ten percent removal from groundwater transport attenuation, meaning that 81 percent (90 percent * 90 percent) of nitrogen from wastewater reaches the bay from these systems..

Data sources used for this source category include:

- Per capita wastewater N loading coefficients: VHP Model.
- Sewer system infrastructure, RI: T. Peters, RIDEM, personal communication, March 21, 2012.
- Sewer system infrastructure, MA: J. Garcia, City of Fall River, personal communication on April 18, 2012; A.M. Teves, City of Taunton, personal communication on April 23, 2012.
- Locations of buildings or structures, RI: RIGIS, 2012.
- Soils information: N. Detenbeck, personal communication, August 16, 2012.
- Average population per building: U.S. Census, 2010.
- N removal efficiency for baseline and upgraded ISDS: A. Gold, personal communication, May 15, 2012; National Environmental Services Center, 2012; and J. Boyd, personal communication, June 21, 2012.

Animal Waste (Agricultural Livestock)

The VHP model uses historical county-level data on livestock populations, together with nitrogen transport coefficients to estimate total nitrogen loadings from livestock, which it calculates as just under 200,000 kg in 2000. The SPARROW model estimates lower nitrogen loadings from manure than the VHP model (46,000 kg). For this loadings category, we assume that SPARROW has the more accurate estimate (because it accounts for any attenuation of nitrogen from livestock within the watershed), so we adjusted the nitrogen transport coefficients from the VHP model so that total loadings from animal waste equal the total estimated by SPARROW. The 3VS model assumes in the baseline scenario that livestock populations remain constant throughout the timeframe of the model, so the amount of nitrogen generated by animals also remains constant. Because loadings from animal waste reach the bay via surface water runoff, precipitation influences the amount of nitrogen loadings to the bay from this source category in the Narragansett 3VS model.

Data sources used for this source category include:

- Historical livestock populations for the watershed: VHP Model.
- Total loadings from animal waste, disaggregated by bay box: SPARROW model data (Milstead 2012).
- Precipitation: National Weather Service Forecast Office. Monthly Weather Summary. Providence (TF Green Airport).

Agricultural Fertilizer

The VHP model uses county-level fertilizer application data to estimate total nitrogen loadings from fertilizer, assuming that 25 percent of total fertilizer applied in the watershed reaches the bay (based on estimates from several studies, including Howarth et al., 1996, Fisher and Oppenheimer, 1991, and Allingham et al., 2002). For 2000, the VHP model estimates that total loadings from fertilizer, including both agricultural and suburban (e.g., lawns, gardens, and golf courses) applications were over one million kg. The SPARROW model estimates loadings from two categories of agricultural fertilizer: "corn, soy, and alfalfa fertilizer" and "other fertilizers." Rather than estimating loadings separately from suburban fertilizer, it includes this source as part of the "developed land" source category. Because agricultural and suburban fertilizer are driven by different factors, we designed the model to estimate them separately. For agricultural fertilizer, we divided SPARROW's loadings estimates (combining both categories of agricultural fertilizer) by the amount of agricultural land in the watershed, yielding fertilizer application rates per hectare. To model loadings from agricultural fertilizer dynamically, we linked these rates to the population of the watershed; as the population increases, the rate of fertilizer application per hectare also increases, reflecting more intensive use of agricultural land. Furthermore, we found that linking fertilizer application rates to population produced an increasing trend of fertilizer use intensity that closely resembled the historical trend seen in the county-level data used in the VHP model. As with loadings from animal waste, loadings reaching the bay from agricultural fertilizer are affected by precipitation in the model.

Data sources used for this source category include:

- <u>Historic fertilizer application rates</u>: VHP Model.
- <u>Disaggregated agricultural fertilizer loadings</u>: SPARROW model data (Milstead 2012).
- <u>Watershed population</u>: NOAA's Spatial Trends in Coastal Socioeconomics (STICS) projections.
- <u>Precipitation</u>: National Weather Service Forecast Office. Monthly Weather Summary. Providence (TF Green Airport).

Residential Fertilizer

To estimate loadings from residential fertilizer use, we first obtained data on the nitrogen content of Rhode Island residential fertilizer sales from Scott's Miracle-Gro Company, which serves approximately 50 percent of the residential fertilizer market in Rhode Island. Doubling the sales data yielded total residential fertilizer sales in Rhode Island. Dividing that number by the population of Rhode Island provided us with an estimate of per-capita nitrogen application rates for residential fertilizer. We then used this parameter to dynamically estimate nitrogen loadings from this source category as a function of total population in the watershed, assuming that per capita nitrogen application rates derived from Rhode Island data would apply to both the Rhode Island and Massachusetts portions of the Narragansett Bay watershed. We then applied the fertilizer nitrogen transport factor from the VHP model, meaning that 25 percent of nitrogen applied in residential fertilizer in the watershed eventually reaches the bay. In addition to being driven by population, loadings reaching the bay from residential fertilizer are influenced by precipitation, as with other surface water runoff categories.

Data sources used for this source category include:

- <u>Fertilizer nitrogen transport coefficients</u>: VHP Model.
- <u>Total residential fertilizer sales in Rhode Island</u>: Gina Zirkle, Scott's Miracle-Gro Company.

- Precipitation: National Weather Service Forecast Office. Monthly Weather Summary. Providence (TF Green Airport).

Atmospheric Deposition Direct to the Bay and via the Watershed

The VHP model estimates nitrogen loadings from atmospheric deposition direct to the bay, as well as from nitrogen that is deposited onto the watershed. For both categories, the VHP model uses a value of 10 kg/ha for 2000. For atmospheric deposition via the watershed, the VHP model uses different nitrogen transport coefficients for three categories of land use: forest (10 percent), agricultural land (20 percent), and urban land (65 percent). In 2000, the VHP model estimates about 280,000 kg in deposition direct to the bay and 1.3 million kg in deposition via the watershed. For the Narragansett 3VS model, we used the same framework to estimate nitrogen loadings from atmospheric deposition, combining deposition rates per hectare with land use-specific transport coefficients. However, we used updated data sources and the SPARROW model to improve the estimates provided by the VHP model.

We used EPA's Community Multi-scale Air Quality (CMAQ) model to obtain more precise and updated data on atmospheric deposition of nitrogen, including historical data for 2002 and projected data for 2020. Spatially explicit data from CMAQ allowed us to estimate separate average deposition rates for each bay box, ranging from 6.2 kg/ha in Box 13 to 12.4 kg/ha in Box 1. Using data from EPA's Section 812 Prospective Analysis of the benefits and costs of the 1990 Clean Air Act Amendments, we developed a trajectory of nitrogen deposition direct to the bay from 2002 (290,000 kg) to 2020 (200,000 kg), reflecting expected reductions in nitrogen emissions from Clean Air Act regulations on power plants and automobiles.

For atmospheric deposition via the watershed, SPARROW estimates total loadings of 460,000 kg in 2002, which is substantially lower than the value estimated by the VHP model. Rather than trying to reconcile these two estimates, which likely involve different definitions of what constitutes atmospheric deposition, we instead estimated three different categories of loadings related to atmospheric deposition:

1. Atmospheric deposition via the watershed, developed land: estimated by multiplying SPARROW's estimate of atmospheric deposition via the watershed by the percent of land area in the watershed that is developed;
2. Atmospheric deposition via the watershed, undeveloped land: estimated by multiplying SPARROW's estimate of atmospheric deposition via the watershed by the percent of land area in the watershed that is not developed; and
3. Other urban stormwater: estimated by calculating total nitrogen loadings from surface water runoff (using a method described in the following section – "impervious surfaces") and subtracting other categories of surface water runoff (i.e., animal waste, agricultural and residential fertilizer, and atmospheric deposition via the watershed on both developed and undeveloped land).

We assume that this third category, "other urban stormwater" includes a portion of the loadings defined as atmospheric deposition via the watershed in the VHP model and a portion of the loadings defined as "developed land" in SPARROW. For 2002, we estimate that loadings to the bay from atmospheric deposition via the watershed were 300,000 kg on undeveloped land and 160,000 kg on developed land. As with other surface water runoff source categories, nitrogen loadings from atmospheric deposition via the watershed are affected by precipitation in the model.

Data sources used for this source category include:

- Historic atmospheric deposition data for 2002 and projected atmospheric deposition data for 2020, disaggregated by bay box: EPA's Community Multi-scale Air Quality model (CMAQ); Dr. Robin Dennis, EPA Atmospheric Modeling and Analysis Division.
- Trajectory of nitrogen emissions from 2002 to 2020: EPA's Second Section 812 Prospective Analysis of the Benefits and Costs of the 1990 Clean Air Act Amendments. Available at: http://www.epa.gov/air/sect812/prospective2.html.
- Land use distribution in the watershed and land use category-specific nitrogen transport coefficients: VHP model.
- Disaggregated nitrogen loadings from atmospheric deposition via the watershed: SPARROW model data (Milstead 2012).
- Distribution of developed land in the watershed: USGS National Land Cover Database (NLCD) 2006 Land Cover.
- Precipitation: National Weather Service Forecast Office. Monthly Weather Summary. Providence (TF Green Airport).

Impervious Surfaces

In order to capture the effects of low impact development and green infrastructure on nitrogen loadings in the watershed, we designed the nitrogen loadings module in the Narragansett 3VS model so that three source categories – residential fertilizer, atmospheric deposition on developed land, and other urban stormwater – are affected by the amount of impervious surface cover in the watershed. To do so, we created a new category of loadings called "surface water runoff" and estimated nitrogen loadings for this category using the Simple Empirical Method Model (or the "Simple Method"). The Simple Method estimates total surface water runoff loadings as a function of (1) impervious surface area, (2) stormwater runoff pollutant concentrations, and (3) annual precipitation. To estimate total surface water runoff loadings in the Narragansett Bay watershed, we used the Simple Method, together with nitrogen runoff concentration data from the National Stormwater Quality Database, local precipitation data, and local impervious surface area data from USGS GIS datasets for 2002. The model also estimates projected future impervious surface cover in each watershed using data from the Integrated Climate and Land Use Scenarios (ICLUS) model. This estimate of total surface water runoff nitrogen loadings is used in the model in two ways:

1. The Surface Water Runoff category is defined in the model to encompass six other source categories: atmospheric deposition via the watershed on undeveloped land, agricultural fertilizer, animal waste, atmospheric deposition via the watershed on developed land, residential fertilizer, and other urban stormwater (see Exhibit 2-10). As noted in the previous section, we estimate

nitrogen loadings in the "other urban stormwater" source category as the difference between total surface water runoff loadings (as estimated using the Simple Method) and all other surface water runoff source categories. For 2002, we estimate that nitrogen loadings from other urban stormwater were 230,000 kg.

2. Of the six source categories that together comprise total loadings from surface water runoff, three categories (atmospheric deposition via the watershed on undeveloped land, agricultural fertilizer, and animal waste) originate on undeveloped land, and three categories (atmospheric deposition via the watershed on developed land, residential fertilizer, and other urban stormwater) originate on developed land. The model assumes that any changes in impervious cover affect loadings in the three "developed land" categories, either by increasing the impervious surface in land already developed or by converting undeveloped land to developed land. As impervious surface area in the watershed increases (due to increased traditional development) or decreases (due to low-impact development or green infrastructure), the estimate of total nitrogen loadings from surface water runoff also increases or decreases. The model then adjusts loadings from the three "developed land" categories in proportion to changes in total nitrogen loadings from surface water runoff. The model does not adjust loadings from the three "undeveloped land" categories as a result of changes in impervious surface; to the extent that any increase in impervious cover results from converting undeveloped land to developed land, the model may overestimate loadings from these categories.

Data sources used for this source category include:

- Simple Method formula for estimating total loadings from surface water runoff: Shaver et. Al (2007), North American Lake Management Society in cooperation with U.S. EPA. Original Simple Empirical Method developed by T. Schueler in 1987 and refined by the Center for Watershed Protection in 2003.
- Nitrogen runoff concentrations: National Stormwater Quality Database (2004), with different values used for open space (0 percent impervious cover) and non-open space (>0 percent impervious cover).
- Precipitation data: National Weather Service Forecast Office. Monthly Weather Summary. Providence (TF Green Airport).
- Impervious cover: USGS National Land Cover Database 2001 Percent Developed Imperviousness Version 2.0. U.S. Environmental Protection Agency. 2011. Integrated Climate and Land Use Scenarios (ICLUS) GIS Tools. Accessed at http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=205305.

DISTRIBUTION OF NITROGEN LOADINGS BY REGION AND SEASON

As described in Section 2-3 and shown in Exhibit 2-2, the Narragansett 3VS model divides the Narragansett Bay watershed into eight subwatershed areas and the bay itself into 14 boxes. This section describes how we disaggregated total nitrogen loadings to Narragansett Bay, both spatially, in terms of subwatershed areas and bay boxes, and temporally, by season.

Spatial Distribution

The Narragansett 3VS model distributes loadings spatially in two ways:

1. By subwatershed area: the independent variables used to derive nitrogen loadings by source category (e.g., population, land use) are mostly estimated at the municipal level. Following the method used in the VHP model, we group the municipalities in the Narragansett Bay watershed into eight regions that roughly correspond to subwatersheds within the Narragansett Bay watershed. The model estimates nitrogen loadings for all source categories, with the exception of atmospheric deposition direct to the bay, at the subwatershed area level.
2. By bay box: nitrogen concentrations and related environmental variables are calculated separately by box. We therefore disaggregate nitrogen loadings into the 14 bay boxes for each source category.

Exhibit 2-11 summarizes how we disaggregated nitrogen loadings from each source category by subwatershed area and by bay box. Using the methods described in the exhibit, we developed mapping factors for each source category to translate subwatershed area-level loadings estimates into bay box-level estimates. As an example, for Box 2, the model estimates total nitrogen loadings from WWTFs by combining 100 percent of nitrogen loadings from WWTFs in the Pawtuxet subwatershed area and 5.7 percent of nitrogen loadings from WWTFs in the Upper Bay subwatershed area. For WWTF and ISDS loadings, we were able to develop mapping factors that related loadings in each subwatershed area to a particular box or boxes, as described in the previous example. For the other loadings categories, however, we lacked data necessary to develop specific mapping factors, so we instead estimated the percent of total loadings in each category entering each box from the watershed (based on the disaggregation methods described in Exhibit 2-11) and multiplied total loadings from all watersheds by these "box shares" to estimate loadings entering each box from each source category. For policy scenarios run with the model, the model first estimates changes in loadings at the subwatershed area level and then translates those changes to the bay box level.

EXHIBIT 2-11. SUMMARY OF DISAGGREGATION OF NITROGEN LOADINGS BY SUBWATERSHED AREA AND BY BAY BOX

SOURCE CATEGORY	DISAGGREGATION BY SUBWATERSHED AREA	DISAGGREGATION BY BAY BOX
WWTFs	We assign loadings from individual WWTFs to the subwatershed areas where the facilities are located.	We assign loadings from individual WWTFs to the bay box to which they discharge (either directly or via rivers in the watershed).
ISDSs	We estimate the relevant non-sewered population of each subwatershed area by multiplying each area's total population by the percent of Rhode Island's population using ISDSs that discharge to the bay. We then multiply that number by the per-capita loading rates for ISDSs.	Using geographic boundaries of subwatersheds within the Narragansett Bay watershed, we developed rough mapping factors to translate loadings by subwatershed area into loadings by bay box.
Surface Water Runoff (Total	Using the Simple Method, we calculate total surface water runoff loadings, using data on impervious cover for each subwatershed area.	As with ISDSs, we used rough mapping factors to translate loadings by

Loadings)		subwatershed area into loadings by bay box.
Animal Waste	We multiply the animal stock in each subwatershed area by loading factors, calibrated to equal total animal waste loadings from SPARROW.	SPARROW provides loadings estimates from animal waste disaggregated by bay box.
Agricultural Fertilizer	We multiply agricultural land in each subwatershed area by nitrogen application rates in agricultural fertilizer, adjusted for population and calibrated to equal total agricultural fertilizer loadings from SPARROW.	SPARROW provides loadings estimates from agricultural fertilizer disaggregated by bay box.
Suburban Fertilizer	We multiply the population of each subwatershed area by per-capita nitrogen application rates for residential fertilizer, applying a nitrogen transport factor.	We distribute loadings from residential fertilizer by bay box according to the distribution of total surface water runoff loadings.
Atmospheric Deposition via the Watershed (Both Developed and Undeveloped Land)	We multiply deposition rates by nitrogen transport factors specific to each land use category, calibrated to equal total atmospheric deposition via the watershed loadings from SPARROW.	SPARROW provides loadings estimates from atmospheric deposition via the watershed disaggregated by bay box.
Other Urban Stormwater	We calculate other urban stormwater loadings for each subwatershed area by subtracting loadings from all other surface water runoff source categories from total surface water runoff loadings.	We calculate other urban stormwater loadings for each bay box by subtracting loadings from all other surface water runoff source categories from total surface water runoff loadings.
Atmospheric Deposition Direct to the Bay	Not applicable (deposition direct to the bay does not pass through the watershed).	We use GIS analysis to map deposition rates (from CMAQ) to bay boxes.

Seasonal Distribution

Because the risk of nitrogen-induced hypoxia is higher during the summer, and because policies aimed at reducing nitrogen pollution focus on summer loadings, we separated nitrogen loadings into summer and winter seasons to the extent possible. For purposes of this report, "summer" refers to the warmer half of the year (i.e., May through October) while "winter" refers to the colder half of the year (i.e., November through April). For WWTF loadings, monthly effluent flow and concentration data enabled us to estimate summer and winter loadings separately, using distinct per-capita loadings parameters for each season. Agreed-upon effluent limits for selected facilities target summer loadings only, so we reduced summer loadings for these facilities and left winter loadings unchanged. For most other loadings categories, we assume that the flow of nitrogen to Narragansett Bay does not vary significantly by season, with the exception of agricultural and residential fertilizer. Based on the assumption that the majority of fertilizer application – both of crops and of lawns – occurs during the spring and summer seasons, the model divides loadings from agricultural and residential fertilizer so that 80 percent of loadings from these categories occur during the summer and 20 percent occur during the winter.

2-7. NITROGEN CONCENTRATIONS

NITROGEN CONCENTRATION BY BOX

In each of the 14 bay boxes, the 3VS model estimates nitrogen concentrations by dividing total nitrogen mass in each box by the average water volume of the box. Total nitrogen mass in each box is a function of four factors:

1) Initial mass of nitrogen (calculated based on observed nitrogen concentrations and the volume of each box);
2) A constant nitrogen loss fraction (set to be 30 percent per year, as described in Section 2-9);
3) Nitrogen loadings from the watershed and atmospheric deposition (described in Section 2-6); and
4) Inflow and outflow of nitrogen to represent nitrogen circulation across bay boxes.

In each time step, the model adjusts the nitrogen mass in each box from the previous time step, removing nitrogen based on the 30 percent annual loss fraction, adding nitrogen based on total loadings from the watershed and atmospheric deposition, and adding and subtracting nitrogen based on inflow from and outflow to adjacent boxes in the bay. The remainder of this section discusses the methodology used to model circulation of nitrogen throughout the 14 bay boxes.

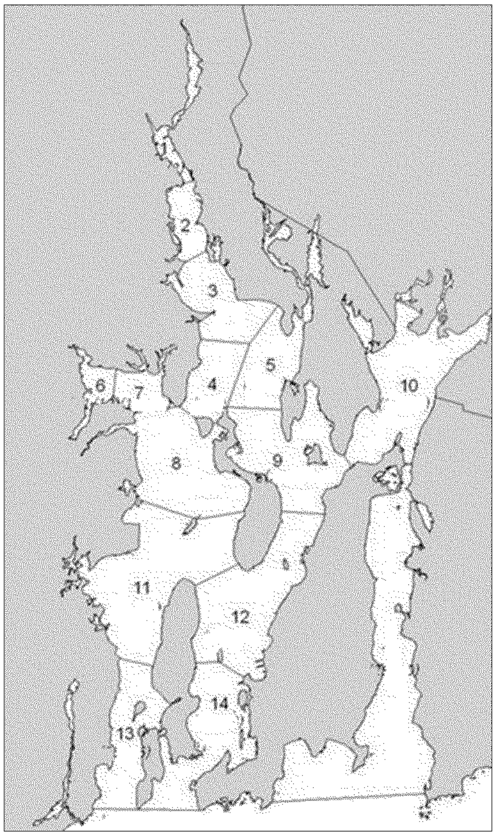
NITROGEN CIRCULATION METHODOLOGY

Our approach to modeling the circulation of nitrogen within Narragansett Bay attempts to remain as faithful as possible to empirical circulation data. As noted in Section 2-3, the model uses a spatial disaggregation from the EcoGEM model (Kremer et al. 2010) which divides the bay into 15 segments, or 'boxes.' For the purposes of the Narragansett 3VS model, we opted to remove the Sakkonet river. It is generally viewed as hydrologically distinct from Narragansett Bay since it is connected by only a narrow strait with limited water exchange. We also merged the two boxes that comprise Greenwich Bay (boxes 6 and 7), due to a lack of sufficiently disaggregated loadings data, yielding a final disaggregation of the bay into 13 distinct boxes (see Exhibit 2-12).

Surface area and volume data for each of these boxes were provided by Mark Brush and Jamie Vaudrey (pers. comm.). To account for circulation between boxes, we used an approach based on residence time (with the common assumption of instantaneous mixing within boxes). We estimated residence times for each box based on the work of Abdelrhman (2004) and refined them using a net system water balance approach.

We employ the following simplifying assumptions to model nitrogen flow between the boxes. We model only net southward flow in the bay at subtidal frequencies, since we lack appropriate temporal resolution with this model to give reasonable estimates of tidal flow between boxes. We divide flow at the base of the Providence River (Box 3) according to Brush (pers. comm.) with 40 percent of the flow going into Box 4 and down the West Passage, and 60 percent of the flow going into Box 5, and down the East Passage. We follow the assumptions of Brush and colleagues (pers. comm.) and disregard lateral flow (e.g. between Boxes 4 and 5, and between Boxes11 and 12 through the gap between Prudence and Aquidneck Island). The one exception to this rule is that 30 percent of the flow exiting Box 4 is vectored into Greenwich Bay (Boxes 6/7) in line with flow calculations presented by Dimilla et al. (2011), which results in a level of contribution from the bay proper to the overall budget of Greenwich Bay that is roughly consistent with estimates of the relative amounts of nitrogen loading to Greenwich Bay from different sources by Granger (2000) and Urish and Gomez (2004).

EXHIBIT 2-12. MAP OF BAY BOXES



Legend

Box 1: Providence River Estuary, North of Fields Point

Box 2: Providence River Estuary, South of Fields Point

Box 3: Upper Bay North (Barrington)

Box 4: Upper Bay West (Warwick Neck)

Box 5: Upper Bay East (Colt State Park)

Box 6: Inner Greenwich Bay

Box 7: Outer Greenwich Bay

Box 8: Upper West Passage (South of Greenwich Bay)

Box 9: Upper East Passage (Bristol)

Box 10: Mount Hope Bay

Box 11: Middle West Passage (Quonset Point)

Box 12: Middle East Passage (South of Prudence Island)

Box 13: Lower West Passage (Dutch Island)

Box 14: Lower East Passage (Newport)

In most cases, this modeling approach and current loadings data produced stable steady state concentrations that closely approximate field observations of nitrogen levels (Krumholz and Oviatt, 2012, Krumholz pers. comm.) for these sections of the bay. In cases where a significant discrepancy between modeled and measured concentrations was observed we adjusted residence times in order to more closely reproduce the empirically observed concentration values. This is the case for Boxes 2, 10, 11, 12 and 13 as presented in Exhibit 2-13. Specifically concerning Box 2, the small volume and high throughput of this box necessitated a modeled residence time of slightly less than half the value calculated by Abdelrhman in order to reconcile inflow and outflow and not result in an unrealistic accumulation of nitrogen in this box.

EXHIBIT 2-13. BAY BOX RESIDENCE TIMES

BOX NUMBER	BOX NAME	LOCAL RESIDENCE TIME OBSERVATIONS* (HOURS)	LOCAL RESIDENCE TIME MODEL INPUT (HOURS)
1	Providence River Estuary, North of Fields Point	67.2	67.2
2	Providence River Estuary, South of Fields Point	85.0	45.0
3	Upper Bay North (Barrington)	109.8	109.8
4	Upper Bay West (Warwick Neck)	132.0	132.0
5	Upper Bay East (Colt State Park)	135.0	135.0
6 & 7	Greenwich Bay	196.8	196.8
8	Upper West Passage (South of Greenwich Bay)	252.0	252.0
9	Upper East Passage (Bristol)	130.0	170.0
10	Mount Hope Bay	132.0	250.0
11	Middle West Passage (Quonset Point)	219.6	350.0
12	Middle East Passage (South of Prudence Island)	262.8	170.0
13	Lower West Passage (Dutch Island)	128.4	200.0
14	Lower East Passage (Newport)	219.4	219.4

* Source: Adelrhman 2004.

To illustrate the methodology explained above, Exhibits 2-14 and 2-15 present the 3VS module in which nitrogen flow is calculated, as well as key equations and sample results of the simulation. Specifically, Exhibit 2-14 shows a simplified version of the nitrogen flow module, with all the inflows and outflows of nitrogen for each bay box. This screenshot is simplified, as residence time, initial mass, and average water volume were removed to reduce the visual complexity of the sketch. The area circled in orange is presented in greater detail in Exhibit 2-15, including a list of the seven equations used to estimate the nitrogen stock for Box 3 and all its flows. The graphs in Exhibit 2-15 compare the model's estimated nitrogen concentration in Box 3 between 2006 and 2011 to observed data. For the model's concentration estimates, we added a random noise factor to reproduce the historical variability in the observed data (see graph on the left). The graph on the right presents nitrogen concentration without the random noise factor, showing the model's calculated concentration as affected by nitrogen loadings and residence times only.

EXHIBIT 2-14. 3VS NITROGEN FLOW MODULE

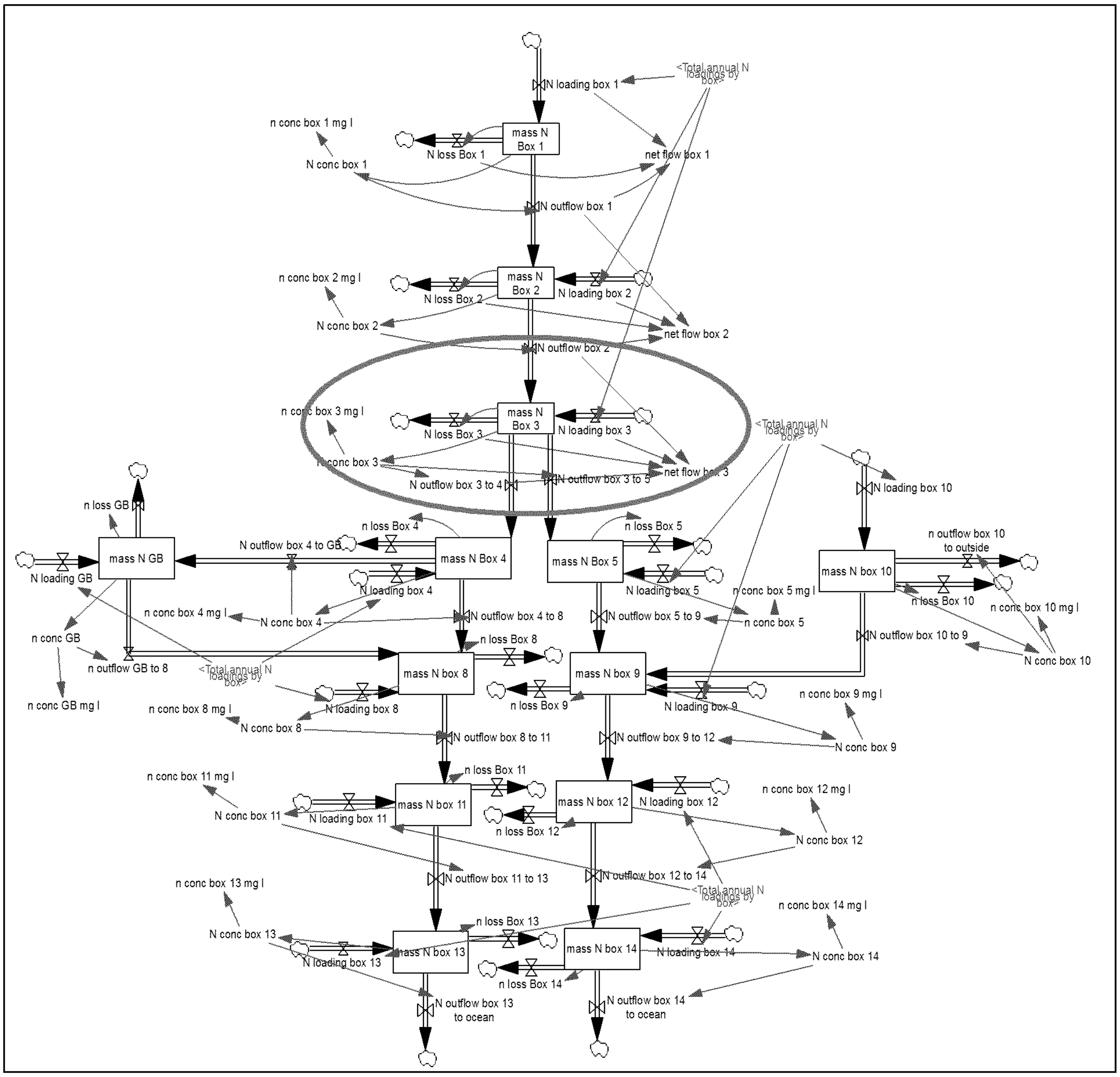


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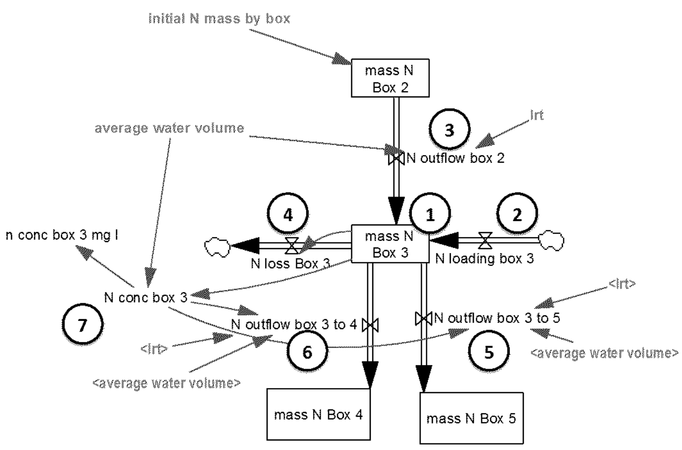
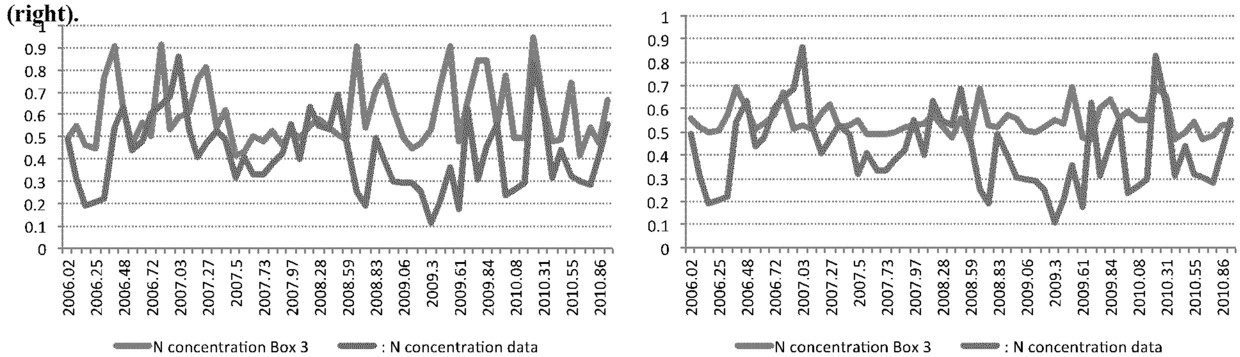
EXHIBIT 2-15. 3VS NITROGEN FLOW: MODEL, EQUATIONS AND RESULTS



1. ***(N stock)*** *Mass N Box 3= INTEG (N Loading Box 3+N Outflow Box 2-N Loss Box 3-N Outflow Box 3 To 4-N Outflow Box 3 To 5,Initial N Mass By Box[BOX3])*
2. ***(N inflow)*** *N Loading Box 3=N Loadings Per Year By Box[BOX3]*
3. ***(N inflow)*** *N Outflow Box 2= (Average Water Volume[Box2]/Lrt[Box2])*N Conc Box 2*
4. ***(N outflow)*** *N Loss Box 3= (Mass N Box 3*0.3)*
5. ***(N outflow)*** *N Outflow Box 3 To 5= (Average Water Volume[Box3]/Lrt[Box3])*N Conc Box 3*0.6*
6. ***(N outflow)*** *N Outflow Box 3 To 4= (Average Water Volume[Box3]/Lrt[Box3])*N Conc Box 3*0.4*
7. ***(N concentration)*** *N Conc Box 3= Mass N Box 3/Average Water Volume[BOX3]*

Units: N mass (Kg N), N flows (Kg n/Year), N concentration (Kg/M3, Mg/L).

N concentration, box 3: with random noise (left), without noise (right).



2-8. POLICY INTERVENTIONS

This section describes how the Narragansett 3VS model simulates the effects of potential policy interventions aimed at reducing nitrogen loadings to Narragansett Bay. It first defines the model's baseline scenario, then describes how users can specify assumptions about financing policy interventions with significant capital costs, and then provides additional detail on eight policy interventions that can be run in the model. For each intervention, we list the category (or categories) of nitrogen loadings affected and summarize our approach for modeling the cost of the intervention as well as its impacts on nitrogen loadings and any other variables.

BASELINE SCENARIO

The nitrogen loadings that are included in the model's baseline scenario include the current and agreed upon nutrient reductions, with no further actions taken to reduce nitrogen loading. Specifically, nitrogen contributions from WWTFs incorporate facility-specific reductions achieved through 2010 (as reflected in compliance and monitoring data), as well as additional agreed-upon reductions at selected plants. The baseline scenario also includes expected nitrogen removal from Phase I and Phase II of the Narragansett Bay Commission's combined sewer overflow (CSO) tunnel.

FINANCING

For each of the policy interventions described below, users can specify annualized costs of the intervention per kg of nitrogen removed. As an alternative approach, for interventions with significant capital costs, the user can use the financing module of the model. This module allows the user to specify assumptions for up to four projects for how significant capital costs might be financed, including (1) the total capital cost to be financed, (2) the length of time for which financing would be secured, and (3) the interest rate. For all estimated costs – both annualized costs and costs estimated through the financing module – the model estimates net present values using a user-specified discount rate (by default, the discount rate is set to 0 percent).

WASTE WATER TREATMENT FACILITIES (WWTFS)

- <u>Category of nitrogen loadings affected</u>: All loadings from WWTFs in the watershed, with agreed-upon reductions included in the baseline.
- <u>Approach to modeling impact on nitrogen loadings</u>: The user specifies a percent reduction in loadings for all WWTFs in the watershed or in one of the specific subwatershed areas. Exhibit 2-16 lists the WWTFs in the Narragansett Bay watershed, noting the subwatershed area in which each facility is located, as well as the bay box that receives its effluent.
- <u>Approach to modeling costs and energy use</u>: The user can specify annualized capital costs and operations and management (O&M) costs per unit of nitrogen reduction for all WWTFs in the watershed. The model provides default values of $158 per kg nitrogen reduced annualized capital costs and $20 per kg nitrogen reduced for O&M costs. We derived these costs from reports estimating the capital and O&M costs required to meet 8 mg/L and 5 mg/L limits at selected facilities in Massachusetts. Instead of using this estimate of annualized capital costs, the user may choose to use the financing module to estimate the total costs of financing the capital investments required for major treatment upgrades. The model also includes an assumption that WWTFs will collectively consume an additional kwh of energy for every 25 kg of nitrogen reduced. The user can specify alternative values for WWTF energy use for nitrogen reduction, though this variable is not included in either the model dashboard or the user interface.

EXHIBIT 2-16. WASTEWATER TREATMENT FACILITIES BY SUBWATERSHED AREA AND BAY BOX

STATE	WWTF NAME	SUBWATERSHED AREA	BAY BOX
Rhode Island	Bristol	Upper Bay	9
	Bucklin	Small Watersheds	1
	Burrillville	Blackstone Above Manville (RI Portion)	1
	Cranston	Upper Bay	1
	East Greenwich	Upper Bay	6
	East Providence	Upper Bay	2
	Fields Point	Upper Bay	1
	Jamestown	Upper Bay	14
	Newport	Upper Bay	14
	Quonset	Upper Bay	11
	Smithfield	Small Watersheds	1
	Warren	Upper Bay	5
	Warwick	Pawtuxet	2
	West Warwick	Pawtuxet	2
	Woonsocket	Blackstone Above Manville (RI Portion)	1
Massachusetts	Attleboro	Small Watersheds	1
	Bridgewater	Taunton Above Bridgewater	10
	Brockton	Taunton Above Bridgewater	10
	Douglas	Blackstone Above Millville (MA Portion)	1
	Fall River	Upper Bay	10
	Grafton	Blackstone Above Millville (MA Portion)	1
	Hopedale	Blackstone Above Millville (MA Portion)	1
	Mansfield	Taunton Lower	10
	Middleborough	Taunton Above Bridgewater	10
	North Attleborough	Small Watersheds	1
	Northbridge	Blackstone Above Millville (MA Portion)	1
	Somerset	Taunton Lower	10
	Taunton	Taunton Mid	10
	Upton	Blackstone Above Millville (MA Portion)	1
	Uxbridge	Blackstone Above Millville (MA Portion)	1
	Worcester / Upper Blackstone Water Pollution Abatement District	Blackstone Above Millville (MA Portion)	1

INDEPENDENT SEWAGE DISPOSAL SYSTEM (ISDS) UPGRADES

- Category of nitrogen loadings affected: All loadings from ISDSs within the watershed boundary that are expected to discharge nitrogen to the bay, defined by those located on soils with high infiltration rates that are connected to the bay or that overlap rivers and streams leading to the bay.
- Approach to modeling impact on nitrogen loadings: The user specifies the percentage of ISDSs to be upgraded for the whole watershed. The user can also specify the nitrogen removal effectiveness for each subwatershed area where ISDSs will be upgraded.

- Approach to modeling costs: The model's uses a default cost assumption of $10,000 per household for upgraded ISDSs. The user can specify a different cost for ISDS upgrades.

ANIMAL WASTE REDUCTIONS

- Category of nitrogen loadings affected: Total loadings from animal waste.
- Approach to modeling impact on nitrogen loadings: The user specifies a percent reduction in loadings from animal waste for the whole watershed.
- Approach to modeling costs: The user specifies costs per kg of nitrogen loadings reduced from animal waste.

AGRICULTURAL FERTILIZER USE REDUCTIONS

- Category of nitrogen loadings affected: Total loadings from agricultural fertilizer use.
- Approach to modeling impact on nitrogen loadings: The user specifies a percent reduction in loadings from fertilizer use across the whole watershed.
- Approach to modeling costs: The user specifies costs per kg of nitrogen loadings reduced from agricultural fertilizer.

RESIDENTIAL FERTILIZER USE REDUCTIONS

- Category of nitrogen loadings affected: Total loadings from residential fertilizer use.
- Approach to modeling impact on nitrogen loadings: The user specifies a percent reduction in loadings from fertilizer use for each subwatershed area.
- Approach to modeling costs: The user specifies costs per kg of nitrogen loadings reduced from residential fertilizer.

OYSTER AQUACULTURE

- Category of nitrogen loadings affected: This intervention allows users to examine the nitrogen removing effects of oyster aquaculture in several of the bay boxes. The model includes data on the total amount of area approved for shellfishing in each bay box (A. Liberti, personal communication on December 3, 2014). The approved acreage ranges from 0 acres in Boxes 1, 2, 3, 5, and 10, to 200-400 acres in Boxes 4 and 7, to as high as several thousand acres in boxes 8, 9, 11, 12, 13, and 14. The model assumes that each farm is one acre in size and produces 100,000 oysters annually after a 2 year start-up period (CRMC 2011; RIDEM 2013; N. Thompson, personal communication on June 2012).
- Approach to modeling impact on nitrogen loadings: We estimate the amount of nitrogen removed through bioharvesting and bioremediation of 100,000 oysters for each of the 20 farms. The user can specify how many farms are established in each bay box or the percentage of total approved area in each box where farms will be developed. We estimate that the total nitrogen removed per farm is approximately 677 lbs/year (or 308 kg/year) (M. Rice, personal communication on September 5, 2012; Newell et al., 2005). We recognize that research is currently being conducted to determine the extent of nitrogen removal by shellfish, and that therefore this estimate may need to be revised in future versions of the model. Note that the user can specify alternative values for this input, though this variable is not included in either the model dashboard or the user interface.

- Approach to modeling costs and other impacts: We estimate annual operating costs of $10,000 per farm (N. Thompson, personal communication on June 2012). We estimate annual revenues of approximately $57,000 per farm (CRMC 2011). We also estimate that each farm employs two people (CRMC 2011). Note that the user can specify alternative values for these inputs, though this variable is not included in either the model dashboard or the user interface.

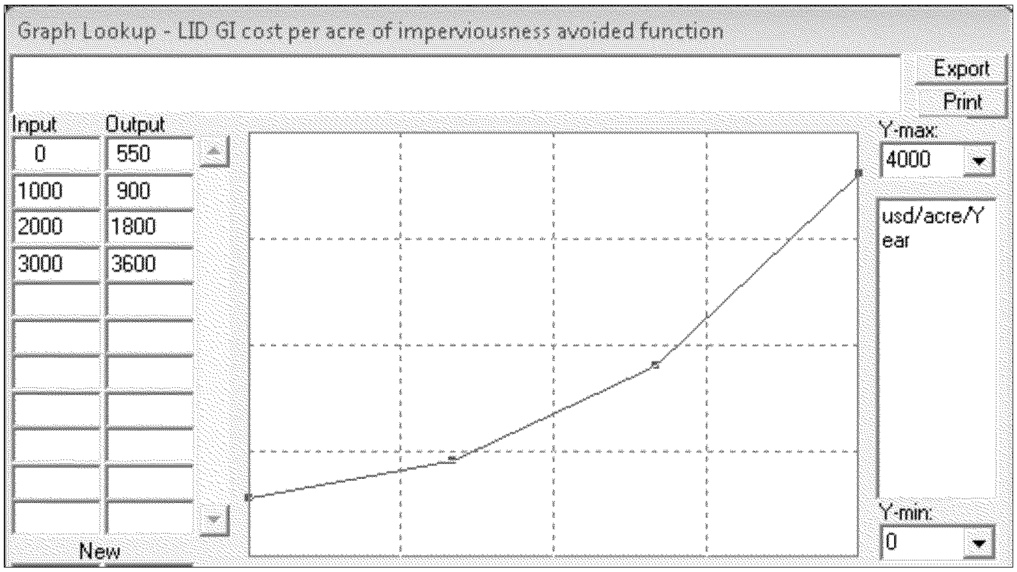
ATMOSPHERIC DEPOSITION REDUCTIONS

- Category of nitrogen loadings affected: Loadings from atmospheric deposition direct to the bay and via the watershed on developed and undeveloped land.
- Approach to modeling impact on nitrogen loadings: As part of the baseline scenario, the model incorporates predicted decreases in atmospheric deposition from national and regional air pollution reduction programs through 2020. These decreases result in a reduction in atmospheric deposition of nitrogen, both direct to the bay and on the watershed. The user can specify an additional reduction in loadings from air deposition for the whole watershed beyond those associated with existing programs.
- Approach to modeling costs: The model currently does not include costs for atmospheric deposition reductions. Future versions of the model can incorporate a feature to allow users to specify costs for this policy intervention.

LID/GI

- Category of nitrogen loadings affected: Loadings from surface water runoff on developed land, i.e., residential fertilizer, atmospheric deposition via the watershed, and other urban stormwater.
- Approach to modeling impact on nitrogen loadings: The model includes projected increases in impervious surface cover in each subwatershed area, based on data from the ICLUS model. The user can specify the percent impervious cover in each subwatershed area that would result from the application of LID/GI, either preventing projected increases (in the case of LID/GI for new development) or decreasing percent impervious cover below initial levels (in the case of LID/GI retrofits). The user can also adjust the baseline projections of future impervious cover, in case updated projection data become available.
- Approach to modeling costs: The model assumes that implementing LID/GI for new development (i.e., preventing any increase in percent impervious cover) has no cost. For LID/GI retrofits (i.e., reducing percent impervious cover below initial values), the model assumes that there would be an increasing cost per acre of imperviousness reduced. As a default assumption, the model uses an increasing cost function with values based on average fees charged per acre of impervious cover by stormwater utilities (Bend Oregon 2014, City of Champaign 2014, City of Raleigh 2014, and Lewiston Maine 2014). The cost curve included in the model for this policy intervention is presented in Exhibit 2-17.
- Other impacts: For the LID/GI intervention, the model also estimates changes to property values that would result from any LID/GI that increases open space around new and existing residential properties. The data and relationships driving this impact are described further in Section 2-9.

EXHIBIT 2-17. COST FUNCTION USED TO ESTIMATE COSTS OF LID/GI RETROFITS



2-9. MODELED RELATIONSHIPS

This section describes the data used to develop environmental and socioeconomic relationships in the Narragansett-3VS model. These relationships form the basis in the model for estimating the effects of nitrogen loading on environmental, social, and economic indicators.

ENVIRONMENTAL RELATIONSHIPS

The environmental relationships described in this section allow the model to translate changes in nitrogen concentration to impacts on various environmental indicators, including growth of macro- and microalgae, water clarity, eelgrass improvement potential, and hypoxia risk. The data underlying these relationships were developed through extensive research, including reviewing existing literature and contacting a number of local scientists who have conducted studies of the environmental conditions in the bay.

Nitrogen Losses In the Bay

Nitrogen loss occurs through sedimentation, denitrifiation and other nitrogen process that vary throughout the bay in space and time. The relationship used in the model simplifies nitrogen loss as a simple function of nitrogen stock, defining it as 30 percent of nitrogen stock lost per year.

<u>Relationship</u>:

*Nitrogen loss (*kg N/year) = *.3 * Nitrogen stock (*kg N/year)

<u>Source</u>: Ed Dettmann, personal communication (2011).

Effect of Nitrogen Loading on Chlorophyll *A*

The relationship between nitrogen loading and Chlorophyll A is specific to Narragansett Bay and was developed and published by Ed Dettmann of the EPA Atlantic Ecology Lab. The values used in the model were estimated using regression analysis of data from Narragansett Bay.

Relationship:

Summer: $Chlorophyll\ a\ (\mu g / L) = 57.5 * (N\ concentration\ in\ water\ (g / m^3)\ )^{2.09}$

Winter: $Chlorophyll\ a\ (\mu g / L) = 10.3 * (N\ concentration\ in\ water\ (g / m^3))^{1.275}$

Source: Dettmann et al. (2005).

Effect of Nitrogen Loading on Relative Sea Lettuce (Ulva) Growth Rate

The estimate of the daily growth rate of ulva is derived from Figure 3 in Teichberg et al. 2010, which represents average daily growth rates of ulva in controlled settings during peak growing season. The regression line is interpreted to be equal to the following:

*Daily growth rate (%) = (Log(annual dissolved inorganic nitrogen concentration (µM)) * 9)/100*

Annual dissolved inorganic nitrogen concentration (µM) is converted to (g N / m^3) by multiplying by *0.014*. By the properties of logarithms, adding *Log(0.014)*9/100*, or *16.685/100* preserves the original relationship when nitrogen is measured in grams per cubic meter.

Relationship:

$Percentage\ growth\ of\ ulva\ per\ day = ((Log(N\ (g / m^3)) * 9 + 16.685)) / 100$

Source: Calculations from Teichberg et al. (2010).

Effect of Micro Algae (Chlorophyll A) on Water Clarity (as Measured by Secchi Depth)

The model estimates water clarity, measured by Secchi depth, as a function of Chlorophyll A, based on a linear regression that uses a quadratic term. We conducted the regression using secchi depth data from water quality monitoring stations in the bay and data on chlorophyll A, measured as the maximum level of the three measures taken at each station (surface, middle or bottom). The regression used 98 observations and resulted in an R^2 of 0.214, with all coefficients significant at the one percent level. Increases in Chlorophyll A decrease Secchi depth with a diminishing effect until Secchi depth reaches 0.5 meters. Minimum Secchi depth is set to 0.5 meters to reflect observed conditions in the bay and the limits of the impact of Chlorophyll A on Secchi depth.

Relationship:

$Secchi\ depth\ (meters) = 2.83 - 0.09*(Chl\ A\ (\mu g / L)\ ) + 0.000776 * (Chl\ A\ (\mu g / L)\ )^2,$

$if\ 0 < Chl\ A\ \ (\mu g / L) <= 39;$

Otherwise Secchi depth (meters) = 0.5

Source: Regression analysis (conducted with Stata V.12) of Narragansett Bay data from the *NOAA National Coastal Assessment Northeast Database: Years 2000 to 2006*. Data and Stata ".do" files available upon request.

Eelgrass Improvement Potential

The metric of eelgrass improvement potential is a semi-qualitative index variable meant to indicate the potential for each bay box to recover eelgrass habitat. It is defined so that it has a minimum value of one (lowest potential for eel grass habitat recovery) and a maximum value of nine (highest potential for eelgrass habitat recovery). The calculation of this index involves two components, designed to capture both the total area where eelgrass could recover and the likelihood that recovery in those areas will be successful. For the first component, the bay boxes are assigned a score of one, two, or three based on the relative area of suitable and very suitable eelgrass area as defined by the 2003 Rhode Island Eelgrass Transplant Suitability analysis (one represents the lowest amount of suitable and very suitable eelgrass, while three represents the highest amount). These suitable and very suitable eel grass areas are believed to benefit from increased Secchi depth. For the second component, bay boxes are assigned a score of one, two, or three, based on the estimated Secchi depth of each box.

The Rhode Island Eelgrass Transplant Suitability Index used for the first component of the eel grass recovery index examines bathymetry, temperature, light, current eelgrass, and historic eel grass. Bathymetry and temperature are used to determine if the area could support eelgrass transplants. Areas with current eelgrass are excluded. The index includes components that account for light penetration and whether the area is known to historically support eel grass. The total area defined as being "suitable" and "very suitable" for eel grass transplant are presented by bay box below in Exhibit 2-18:

EXHIBIT 2-18. EEL GRASS AREA BY BAY BOX

BAY BOX	BOX NAME	ACRES OF SUITABLE AND VERY SUITABLE EELGRASS TRANSPLANT HABITAT
1	Providence River Estuary - North of Fields Point	63
2	Providence River Estuary - South of Fields Point	223
3	Upper Bay North	560
4	Upper Bay West	35
5	Upper Bay East	119
6&7	Greenwich Bay	454
8	Upper West Passage	176
9	Upper East Passage	255
10	Mount Hope Bay	375
11	Middle West Passage	111
12	Middle East Passage	86
13	Lower West Passage	73
14	Lower East Passage	63

Since the suitable transplant area excludes current eelgrass areas, the model does not suggest areas where decreased light conditions would harm the eelgrass. As the focus of the 3VS approach is on interventions that improve the health of the bay, the transplant suitability data are appropriate for model purposes. These data allow the model to use the wealth of primary research on areas that would benefit from increased light penetration incorporated in the Rhode Island Eelgrass Transplant Suitability Index.

Relationship:

Relative area of eelgrass transplant suitability is the first factor in the metric as shown in Exhibit 2-19:

EXHIBIT 2-19. RELATIVE AREA OF EELGRASS TRANSPLANT SUITABILITY

RELATIVE AREA OF EELGRASS TRANSPLANT SUITABILITY	BAY BOXES	ASSIGNED VALUE
Low	1, 4, 12, 13, 14	1
Medium	2, 5, 8, 11	2
High	3, 6 & 7, 9, 10	3

Changes in Secchi depth in each box is the second factor in the metric as shown in Exhibit 2-20:

EXHIBIT 2-20. RELATIVE SECCHI DEPTH

RELATIVE SECCHI DEPTH	SECCHI DEPTH VALUES	ASSIGNED VALUE
Low	0.5 to 1.2	1
Medium	1.2 to 1.9	2
High	1.9 to 2.83	3

Multiplying these factors creates the eelgrass metric as shown in Exhibit 2-21:

EXHIBIT 2-21. EELGRASS METRIC

CATEGORY	PRODUCT OF ASSIGNED VALUES	INTERIM METRIC COMBINATIONS
Low potential for eelgrass improvement	1, 2	• Low area and low light • Medium area/light with low area/light
Medium potential for eelgrass improvement	3, 4	• High area/light with low area/light • Medium area with medium light
High potential for eelgrass improvement	6, 9	• Medium area/light with high area/light • High area and high light.

Sources: Short, F., Burdick, D., and J. Kaldy. (1995); 2003 Rhode Island Eelgrass Transplant Suitability Metadata. Available at: http://www.narrbay.org/d_downloads/D_Biological/D_habitat/eelgrtrans.htm

Hypoxia Risk

The creation of hypoxia in the bay is complex process. To capture hypoxia risk in the model, we created a semi-qualitative index that seeks to represent the following three known risk factors of hypoxia:

- *Chlorophyll A* - Increased levels of Chlorophyll A in summer months are commonly believed to contribute to hypoxia risks.

- *Location in the bay* - Different areas of the bay have different levels of susceptibility to hypoxia based on their specific geophysical characteristics.
- *Precipitation* - Higher levels of precipitation may lead to greater stratification in the bay, contributing to the creation of hypoxia.

The model ranks each bay box on a scale of one to three for each of these factors, and the sum of the three scores represents the total hypoxia risk index (with potential values ranging from three to nine), meant to represent the potential risk of hypoxia during the summer season.

Relationship: The relationship is presented in Exhibits 2-22 and 2-23

EXHIBIT 2-22. HYPOXIA RISK METRIC COMPONENTS

COMPONENT RISK LEVEL (POINTS)	CHL A JUNE - AUG AVERAGE (µg/l)	LOCATION IN THE BAY (BY BOX NUMBER)	PRECIPITATION (INCHES FROM JUNE TO AUG)
High (3)	>20	1, 2, 3, 6, 7	>13
Medium (2)	>5 and ≤ 20	8, 4, 5, 9, 10	>9 and ≤ 13
Low (1)	>0 and ≤ 5	11, 12, 13, 14	≤9

EXHIBIT 2-23. HYPOXIA RISK METRIC SCORING

TOTAL RISK LEVEL	SUM OF POINTS	INTERIM METRIC COMBINATIONS
High	8, 9	• All high risk factors (9) • Two high risk factors and one medium risk factor (8)
Medium	6, 7	• Two medium risk factors and one high risk factor (7) • Two high risk factors and one low risk factor (7) • One each high, medium, and low risk factors (6) • Three medium risk factors (6)
Low	3, 4, 5	• Two low risk factors and one high risk factor (5) • Two medium risk factors and one low risk factor (5) • Two low risk factors and one medium risk factor (4) • All low risk factors (3)

Sources: Bricker et al. 2003, precipitation data from TF Green airport available upon request.

Fin Fish Landings

The model estimates changes in commercial fin fish landings using an empirical relationship between finfish abundance and nitrogen loadings from Figure 3 in Breitburg et al. 2009. This study estimates the relationship between nitrogen loadings and fisheries landings of mobile species in estuaries and semi-enclosed seas from sites across the globe.

The modeled relationship is an inverted "U" shape, meaning that depending on the baseline nitrogen concentration in a given water body, increasing nitrogen loadings can cause improvement or decline in fisheries landings. For the Narragansett Bay 3VS model, we assume that at current levels of nitrogen loading, increased nitrogen will decrease commercial fin fish landings according to the relationship presented below. We note, however, that local experts do not agree on the position of Narragansett Bay on this u-shaped curve, (i.e., they debate whether increasing nitrogen would cause improvement or decline in fisheries landings).

The 3VS model uses this relationship to calculate the change in the commercial landings relative to baseline conditions, which are based on estimates of commercial finfish caught in Narragansett Bay. We obtained statewide commercial fish landings data (pounds and dollar value) from the RIDEM Standard Atlantic Fisheries Information System (SAFIS) Dealer Reports for 2010. We assume that five percent of statewide finfish catch comes from the bay, based on Tyrell, Devitt and Smith (1994) and personal communication with John Scotti, Senior Fisheries Specialist at Cornell University (2012), and with Phil Colarusso, Ocean and Coastal Protection Unit USEPA Region I (2012). Based on that assumption, the model estimates that baseline commercial finfish caught in Narragansett Bay is 2,140,519 pounds, valued at over $1,150,000. The model uses the relationship below to estimate the change in the mass of finfish catch, relative to initial catch, and then multiplies that ratio by $1.15 million to estimate the value of finfish catch at each time step.

<u>Relationship</u>:

where x is the log annual nitrogen loadings in $\log_{10}$kg km^{-2} year^{-1}

and f is fisheries landings in log (kg km^{-2} year^{-1})

<u>Sources</u>: Breitburg et al. (2009); Tyrell et al. (1994); John Scotti, personal communication (2012); and Phil Colarusso, personal communication (2012).

SOCIOECONOMIC INDICATORS AND RELATIONSHIPS

Much of the demographic and socioeconomic data used in the model comes from the National Oceanic and Atmospheric Administration's (NOAA) Spatial Trends in Coastal Socioeconomics (STICS) database. This database, maintained by NOAA's National Ocean Service Special Projects Office, provides data for EPA's National Estuary Program watersheds, including the Narragansett Bay watershed. Data are available for 42 demographic variables, including population, employment, and labor force, for every five years from 1970 to 2040. As a general note, the model allows the user to calculate net present values for all monetized impacts (e.g., property value impacts or property tax impacts), using a user-specified discount rate (by default, the discount rate is set to 0 percent).

Beach Visits

The Narragansett 3VS model includes visitation data for seven beaches located within the study area (see Exhibit 2-24): Barrington Town Beach and Conimicut Point Beach (Box 4), City Park Beach and Goddard Park Beach (Box 6), Gorton's Pond and Oakland Beach (Box 7), and Narragansett Town Beach (Box 13) (Marisa Mazzotta, personal communication May 2, 2012). We did not include visitation data for state beaches in the model, as these beaches are located along the coast outside of the bay.

EXHIBIT 2-24. BEACHES WITH VISITATION DATA INCLUDED IN THE NARRAGANSETT 3VS MODEL

BEACH	GENERAL AREA	BAY BOX	ANNUAL VISITATION (NUMBER OF VISITS)
Barrington Town Beach	Upper Bay	4	3,300
Conimicut Point	Upper Bay	4	2,600
City Park Beach	Greenwich Bay	6	4,600
Goddard Park Beach	Greenwich Bay	6	220,000
Gorton's Pond	Greenwich Bay	7	810
Oakland	Greenwich Bay	7	11,000
Narragansett Town Beach	Lower Bay	13	430,000

Based on the results of a doctoral dissertation on the Peconic Bay (Diamantides, 2000), we estimate that a one percent change in water clarity depth (measured by Secchi depth) translates into a 0.56 percent change in the number of beach visits. As an indicator of the economic value of the resulting change in beach visits, we use the consumer surplus per beach visit; lacking reliable data on average consumer expenditures per visit, the consumer surplus provides a measure of the overall value of each visit to the visitor, or excess value enjoyed by each visitor beyond what he or she might have spent on the visit. We estimate that the consumer surplus per visit is $7.74 (USD 2011), based on a Peconic Estuary recreation survey conducted in 1995 and a 1998 study by Kline and Swallow (Opaluch et al., 1999; Kline and Swallow, 1998).

Property Value

Water Clarity

The model uses a relationship between changes in water clarity and coastal property value based on three studies that provide estimates of the percent change in property value for waterfront properties resulting from changes in Secchi depth (Gibbs et al., 2002; Walsh, Milon and Scrogin, 2010; and Boyle et al., 1998). Based on these studies, we estimate that a one meter increase in Secchi depth results in a three percent increase in property value.

For the model, we estimate waterfront residential property values for the bay using 2011 American Community Survey Census data which provides median property values for owner-occupied residential structures in block groups adjacent to the bay (U.S. Census Bureau, 2011). We provide aggregate property values at the subwatershed area level for use in the model, which are calculated using the median property values for the block groups in each subwatershed area, multiplied by the total number of owner-occupied residential structures in each area. Because property value data from the Census is self-reported by owners of owner-occupied structures, the values may be somewhat overstated. Conversely, the fact that the American Community Survey Census dataset does not include values for non-owner occupied structures likely results in an underestimate of aggregate property value in the model. In addition, it is likely that changes in water clarity would also affect the values of commercial properties, though we were not able to find studies that specifically looked at commercial properties. Because the model does not capture this effect, it is likely that it underestimates total property value impacts related to water clarity.

Open Space

For the LID/GI policy intervention, the model also captures the expected impact of increasing open space near residential properties. This impact reflects the assumption that low-impact development and green infrastructure would result in an increase in open space near residential properties, relative to traditional development. A meta-analysis conducted by EPA suggests that an increase in open space in new development increases the property value of new units, and – to a lesser extent – of existing units near the new development. The ICLUS projections that the model uses for baseline estimates of future projected impervious cover also provide projections of changes in housing density, which we used to estimate the number of new units in each subwatershed area over time. Using regression parameters from EPA's analysis (Mazzotta et al., 2014), we relate changes in percent impervious cover to increases in property value for new and existing units. This relationship is modified by several variables that the user can adjust, including:

- The percent of LID/GI that involves increased open space surrounding new units (default value: 100 percent)
- The maximum area surrounding new units that can be turned into new open space (default value: 10 percent)
- The percent of existing units that have new open space within a 500-meter radius (default value: 100 percent).

GDP

GDP is calculated using a supply side approach (extended Cobb-Douglas production function), while ensuring macroeconomic consistency by tracking the demand side of the equation (GDP = consumption + investment + government spending + net export). The main factors used to calculate GDP are capital (an accumulation of investment), labor and productivity. GDP for the primary sector includes agriculture (crop production), livestock, fishery and forestry. GDP for the services sector includes consumer surplus of tourism expenditure. GDP is estimated for the whole Narragansett Bay, using average per capita economic data (State Accounting) from Rhode Island and Massachusetts. For the majority of scenarios that the model is designed to run, the primary variable affecting GDP that might be affected by any policy interventions would be fisheries production as represented by the value of finfish landings. Because this sector composes a relatively small portion of GDP in this region, overall GDP is not significantly affected in most uses of the model.

Per Capita Disposable Income

Household income is calculated by subtracting taxation from total household revenues (calculated by summing up GDP and all the additional monetary flows from the public to the private sector, e.g. private transfers and debt interest payment). The calculation of household accounts is defined in the System of National Accounts (SNA) and the Social Accounting Matrix (SAM) that are also applied at the State level. None of the policy interventions currently included in the model have any effect on per capita disposable income.

Property Tax Effect

The model estimates property tax using a 1.52 percent tax rate, which is multiplied by the value of owner occupied structures in the bay. The model calculates changes in tax revenue in response to changes in property value caused by changes in water clarity and/or changes in open space. In reality, any large changes in property values would likely cause property tax rates to shift to minimize the overall impact on government revenues. This indicator is meant to represent the magnitude of the effect of changes in property values on taxation policies, rather than being an exact estimate of a particular change in government revenue.

Energy Use

Energy demand is estimated using four main drivers: GDP, population, energy prices and technology (energy efficiency). Changes in these four drivers are reflected in energy demand using elasticity factors to represent the strength of each specific causal relation. In particular, GDP and population have a positive causal relation with energy demand, while energy prices and technology have a negative causal relation with energy demand. Among the policy interventions currently included in the model, only changing WWTF treatment has any impact on energy use, and only among the WWTF power consumption portion of energy use.

2-10 SUMMARY OF ADDITIONAL RESEARCH

This section summarizes additional research conducted as we developed the Narragansett 3VS model. As noted in Section 2-4, there are several aspects of the Narragansett Bay system that we were not able to include in the model. The research presented in this section includes additional information related to the data sources that we used to develop the model, other models that indirectly guided the development of the Narragansett-3VS model, data sources that could contribute to future versions of the model, and data sources that we determined did not fit the scale and scope of this model. Exhibit 2-25 presents additional research conducted for environmental relationships. Exhibit 2-26 lists information on research conducted for social and economic relationships. Exhibits 2-27 and 2-28 present information on research conducted into low impact development and green infrastructure. Exhibit 2-27 summarizes data sources that could potentially be usable for future development of the model, while Exhibit 2-28 summarizes data sources that we determined were not applicable for the Narragansett-3VS model.

EXHIBIT 2-25. SUMMARY OF ADDITIONAL RESEARCH INTO ENVIRONMENTAL RELATIONSHIPS

TOPIC	SOURCE	SUMMARY
Circulation	Dettmann, E.H. 2001. Effect of Water Residence Time on Annual Export and Denitrification of Nitrogen in Estuaries: A Model Analysis. *Estuaries*, Vol. 24, No. 4., p. 481-490. August.	This source provides background information on residence time and denitrification for 11 estuaries across the world, including Narragansett Bay. As noted in the environmental relationships section, the model uses a source more specific to Narragansett Bay (Abdelrhman 2005) for residence time. Also noted in the environmental relationships section, Ed Dettmann, USEPA Atlantic Ecology Division, provided a denitrification coefficient of 30 percent annually for Narragansett Bay.
Circulation	Hill, B.H., Bolgrien, D.W. 2010. Nitrogen Removal by Streams and Rivers of the Upper Mississippi River Basin. *Biogeochemistry*. doi: 10.1007/s10533-010-9431-8. April.	This source provides background information on nitrogen in streams and rivers, which is not included in the model, but may be useful in modeling efforts that focus more on river and stream environments.
Circulation	Kellogg, D.Q. et al. 2010. A Geospatial Approach for Assessing Denitrification Sinks Within Lower-Order Catchments. doi: 10.1016/j.ecoleng.02.006. *Ecological Engineering*.	This source provides background information on denitrification processes. As noted in the environmental relationships section, Ed Dettmann, USEPA Atlantic Ecology Division, provided a denitrification coefficient of 30 percent annually for Narragansett Bay, which is used in the current version of the model.
Circulation	Vaudrey, J.M.P., Kremer, J.N. Narragansett Bay EcoGEM Model, 2006. V. 10.21.11. Department of Marine Science, University of Connecticut. Funded by Coastal Hypoxia Research Program, National Oceanic and Atmospheric Administration "Modeling Tools to Understand and Manage Hypoxia: Application to Narragansett Bay. Grant NA05NOS4781201.	This source provides background information on circulation models for Narragansett Bay.
Eelgrass	Thursby, Glen. United States Environmental Protection Agency - Atlantic Ecology Division, Personal Communication. 2012.	Dr. Thursby discussed the possibility of using Secchi depth to determine light extinction coefficient, but this approach was not directly applicable to the model because of insufficiently detailed bathymetry and Secchi depth data. However, the fundamentals of these relationships have been incorporated into the qualitative eel grass metric. Future versions of the model may benefit from Dr. Thursby's bio-optical model.
Eelgrass	Latimer, J and S. Rego. 2010. Empirical Relationship between eelgrass extent and predicted watershed-derived nitrogen loading for shallow New England estuaries. Estuarine, Coastal and Shelf Science 90 p. 231-240.	This source provides information on the effect of nitrogen loadings on eelgrass habitat. In developing the Narragansett 3VS model we chose to focus environmental impacts on changes in nitrogen concentration where possible to allow for disaggregation by bay box.

Hypoxia	Codiga, D., Stoffel, H., Deacutis, C., Kiernan, S., and C. Oviatt. 2009. Narragansett Bay Hypoxic Event Characteristics Based on Fixed-Site Monitoring Network Time Series: Intermittency, Geographic Distribution, Spatial Synchronicity, and Interannual Variability. Coastal and Estuarine Research Federation. Published online: May 23. Deacutis, C.F., D. Murray, W. Prell, E. Saarman, L. Korhun. 2006. Hypoxia in the Upper Half of Narragansett Bay, RI, During August 2001 and 2002. Northeastern Naturalist Vol 13, pp. 173-198. Melrose, D.C., Oviatt, C.A., and Berman, M.S. 2007. Hypoxic Events in Narragansett Bay, Rhode Island, during the Summer of 2001. Estuaries and Coasts, vol. 30, no. 1, pp. 47-53.	These sources provide additional background on hypoxia in Narragansett Bay.
Shellfish Growth Rate	Weiss et al. 2002. The effect of nitrogen loading on the growth rates of quahogs (Mercenaria mercenaria) and soft-shell clams (Mya arenaria) through changes in food supply. Aquaculture Vol. 211, pp. 275-289.	In developing the 3VS model, we explored including a relationship between nitrogen loadings and shellfish growth rate. However, the available data on this relationship did not appear to capture the full range of effects of nitrogen loading on growth rate.

EXHIBIT 2-26. SUMMARY OF ADDITIONAL RESEARCH INTO SOCIAL AND ECONOMIC RELATIONSHIPS

TOPIC	SOURCE	SUMMARY
Beaches	Rhode Island Department of Health, Beach Program http://www.health.ri.gov/beaches/	Rhode Island Department of Health collects data on beach closures and water quality for 114 licensed facilities (72 licensed saltwater beaches and 42 licensed freshwater beaches). In addition, a small number of unlicensed beaches were sampled for the first time in 2011. Sampling frequencies range from once a week to once a year depending on the history of individual beaches, and some beaches are exempt from sampling. These data are not currently incorporated into the model because beach closures are driven by pathogen loadings rather than nitrogen loadings; however, should future versions of the model incorporate data on pathogen loadings, it may be desirable to model beach closures. In addition, the Department of Health may be able to provide information on health-related impacts associated with pathogen loadings.
Property Value	Poor, P. Joan, KL Pessagno, RW Paul. Exploring the hedonic value of ambient water quality: A local watershed based study. Ecological Economics, 2007, vol. 60, issue 4, pages 797-806.	This is a hedonic analysis of the impact of ambient water quality in the St. Mary's River watershed (located in southern Maryland) on residential property sales throughout a watershed. The specific water quality measures considered are total suspended solids (TSS) and dissolved inorganic nitrogen (DIN). The study finds that a 1 mg/L change in ambient inorganic nitrogen changes property values by 8.8 percent, averaged over properties both on the waterfront and further away from the water. We did not use this relationship for the model because the water quality samples used for this study came mostly from small streams within the watershed. For Narragansett, our focus was on nitrogen concentrations within the bay, not within streams in the surrounding watershed.
Property Value	Langworthy, Malia K. 2007. Open Space Financing in Seattle: A Closer Look at the Effects of Open Space on Property Values, City Revenues and Housing Affordability. University of Washington.	This paper examines the relationship between proximity to urban parks and the financial return to property owners, developers, and the public in the form of higher property values, especially in dense urban areas. The paper explores how open space (mainly urban parks) cause property values to rise and in turn displace low-income residents and negatively impact housing affordability. We determined that the Gibbs et al.; Walsh, Milon, and Scrogin; and Boyle et al. studies were better suited for the Narragansett 3VS model due to the fact that this study is more focused on how urban parks affect housing affordability.

Tourism	Hayes, Karen M., Timothy J. Tyrrell, Glen Anderson. "Estimating the Benefits of Water Quality Improvements in the Upper Narragansett Bay." Marine Resource Economics 7 (1992): 75-85.	This study involved a water quality survey designed to obtain information about the value Rhode Island residents place on improved water quality in the bay. The study used the contingent valuation approach and responses from 435 residents to a 1985 survey about how they would value two water quality changes -- improvements to allow safe swimming and improvements to allow shellfishing in the Upper Bay. The survey was conducted in 1985, so we felt that the results were too dated to be used in the model. In addition, we were not able to develop quantitative relationships between nitrogen concentrations and safe swimming and shellfishing in the Upper Bay; these activities are more directly affected by loadings of pathogens rather than nitrogen.
Tourism	Tyrrell, Timothy J., Maureen F. Devitt, and Lynn A. Smith. The Economic Importance of Narragansett Bay. Final Report Prepared for: The Rhode Island Department of Environmental Management - Narragansett Bay Project and The Rhode Island Sea Grant College Program. November 4, 1994.	This study provides value estimates for Bay-related industry jobs and wages; Bay-related tourism jobs, wages, and revenues; revenues for commercial fish catch from the bay; total property value in Bay communities; Bay recreation-related visitors, revenues, jobs, wages, and expenditures; State-wide recreational fishing trips and related expenditures; and the budget for research and regulation of the bay. Because the data were collected in 1994, we felt that the data were too dated to be used in the model. In addition, a relationship between nitrogen concentration and tourism would need to be established before these data could be used in the model.
Tourism	Colt, Ames, Timothy Tyrrell, and Virginia Lee. Narragansett Bay Summit 2000 White Paper. Marine Recreation and Tourism in Narragansett Bay: Critical Values and Concerns. Working Draft. April 11, 2000.	This study provides statewide sales revenues from travelers and tourists, and associated wages and jobs. It provides an estimate of total annual Bay-related outdoor recreation activities ($2 billion). The study cites results of Tyrrell, Devitt and Smith's 1994 study "The Economic Importance of Narragansett Bay" for estimates of the bay's contribution to tourism revenues. It provides net willingness to pay for marine-based outdoor recreation, average yachting event expenditures, recreational fishing expenditures (all statewide, not Bay-specific). It also provides a qualitative discussion of the economic, social, and environmental effects of tourism and recreation. In order for this information to be used in the model, we would need to establish a relationship between nitrogen concentration and tourism.
Tourism	Pacheco, Andrada I., and Timothy J. Tyrrell. The Economic Value of Narragansett Bay: A Review of Economic Studies. March 2003.	This is a review of studies estimating values of the Narragansett Bay ecosystem which cites findings from Tyrrell and Harrison (2000) for the value of ecosystem services in the bay ($2 billion in 1994 dollars). It provides summary tables listing the findings of various studies related to ecosystem services - including the value of raw materials, food production, recreation, cultural, industrial and commercial services of the bay. In order to use these values in the model, we would need to establish a relationship between nitrogen concentration and the ecosystem services valued.

Tourism	Tyrrell, Timothy J. Rhode Island Travel and Tourism Research Report. University of Rhode Island, Department of Resource Economics. Volume 22, Number 1. April 2005.	Provides statewide data on the travel and tourism economy. Also provides city and town level data on tourism industry wages and output. In order to use these values in the model, we would need to establish a relationship between nitrogen concentration and tourism.
Tourism	National Coastal Condition Report III, Chapter 9: Health of Narragansett Bay for Human Use. December 2008.	Provides a variety of tourism-related data for the bay, including beach closures data (same data as on the RIDEM Beaches website); the number of registered boats in Rhode Island in 2002; and the annual commercial fish catch (statewide) and estimates for the lobster and quahog catch from the bay (we use more updated data on for commercial fish landings in the model than what are provided here). In order for these data on tourism to be used in the model, we would need to establish a relationship between nitrogen and tourism.
Tourism	Hellin D, Starbuck K, Terkla D, Roman A and Watson C (2011). 2010 Massachusetts Recreational Boater Survey. Massachusetts Ocean Partnership Technical Report #OC.03.11.	Recreational boating in Massachusetts' coastal and ocean waters contributed $806 million to the Massachusetts economy in 2010. These data are not used in the model because they are not applicable to Narragansett Bay.
Tourism	NOAA Coastal County Snapshots Application (http://www.csc.noaa.gov/digitalcoast/tools/snapshots/)	Provides data on wages, goods and services attributable to tourism and recreation. However, the estimates include coastal activity in the Washington, Newport, and Providence counties. In order to be able to use these data in the model, would need to establish a relationship between nitrogen concentration and tourism and also identify the subset of these data that is applicable specifically to the bay.
Tourism	Rhode Island Department of Administration, Division of Planning, Office of Strategic Planning and Economic Development. Five-Year Update - Rhode Island Comprehensive Economic Development Strategy. March 11, 2010. http://www.planning.ri.gov/ed2/2010CEDS.pdf	Provides information on the Rhode Island's economic condition and presents the state's overall economic development vision and objectives. Provides useful qualitative information about the role that the bay plays in the statewide economy, but does not provide Bay-specific tourism data.
Tourism	Ocean Special Area Management Plan, Volume 1, Chapter 6: Recreation and Tourism (http://seagrant.gso.uri.edu/oceansamp/documents.html)	Describes how in the past Narragansett Bay was a popular site for yacht racing activities and regattas. The plan states that coastal tourism in RI is very seasonal, with coastal communities doubling and tripling in population during the summer months. Provides qualitative information about the bay's tourism but does not provide Bay-specific quantitative data.

EXHIBIT 2-27. SUMMARY OF ADDITIONAL RESEARCH INTO LOW-IMPACT DEVELOPMENT AND GREEN INFRASTRUCTURE: POTENTIALLY USABLE FOR FUTURE MODEL DEVELOPMENT

TOPIC	SOURCE	SUMMARY
LID/GI	"Improving Water-Quality in Urban Watersheds Using a High-Efficiency Street Cleaning Program," City of Cambridge, MA	Presentation discusses potential for reducing phosphorus loadings through "high-efficiency" street cleaning in the Charles River watershed. Presents results of using Source Loading and Management Model (WinSLAMM) to simulate phosphorus load reduction from different street cleaner technologies. If we could obtain preliminary results data, we could potentially simulate the effects of non-structural LID/GI interventions like street cleaning on phosphorus loads. Currently 3VS does not model phosphorus.
LID/GI	"An Optimization Approach to Evaluate the Role of Ecosystem Services in Chesapeake Bay Restoration Strategies," EPA ORD, October 2011	Report on implementing a framework for assessing ecosystem service impacts of Green Infrastructure approaches to meeting the nutrient and sediment TMDLs in Chesapeake Bay. Analysis uses highly spatially explicit data sources and modeling tools to determine appropriate implementation of point source controls, agricultural BMPs, and urban stormwater BMPs. Analysis accounts for direct (nutrient and sediment reduction) benefits as well as "bonus ecosystem service" (carbon sequestration, air pollution reduction, flood control) benefits. Illustrates how to model implementation of LID BMPs (both agricultural and urban) in a highly spatially explicit way. Currently, the Narragansett 3VS model does not include the level of spatial precision necessary to reproduce this particular effort.
LID/GI	"BMP Performance Extrapolation Tool for New England," EPA, 2011	This tool can estimate removal efficiency for TP, TSS, and Zinc (but not TN) for biofiltration, dry pond, grass swale, gravel wetland, infiltration basin, infiltration trench, and porous pavement. The important elements for estimating stormwater BMP removal efficiency using this tool to estimate pollutant removal (e.g. P or N when available) or flow volume (IC) reduction for LID BMPs are: type of BMP, design storm volume (expressed as inches over area of IC treated by BMP), and amount of impervious area being treated in the watershed with BMPs. Need to input source area (e.g., comm/res/ind), BMP type, pollutant, and depth of treated runoff (0-2 inches). Could be useful if 3VS is extended to other pollutants.
LID/GI	"Estuary Data Mapper," EPA	Provides spatial data for estuarine watersheds, including land use/land cover, imperviousness (current and projected), and housing density (current and projected). Also has estuarine water quality, precipitation annual and monthly averages, nitrogen deposition, estimated estuarine N and P loads and sources, and projected N and P loads under climate and land-use change scenarios. This could provide a consistent source of useful input data if the 3VS model is

		applied to other estuaries.
LID/GI	"Blue Cities Guide: Supplemental Materials," the appendices to "Blue Cities Guide: Environmentally Sensitive Urban Development," Charles River Watershed Association, September 2008	Provides extensive descriptions of LID/GI projects, ranging from permeable pavement to green rooftops. Includes cost/effectiveness and implementation examples. Could be used to predict outcomes of using specific LID/GI technologies, though the 3VS model currently focuses on the impacts of regional implementation of LID/GI, rather than specific technologies.
LID/GI	"Forging the Link: Linking the Economic Benefits of Low Impact Development and Community Decisions," UNH Stormwater Center Resource Manual, 2011	Chap 2 reports the removal efficiency of various BMPs for N, P, and TSS as well as O&M costs. Chap 3 looks at case studies and compares conventional to LID costs across several areas to show where investment leads to offsetting savings elsewhere. Maintenance costs are highly variable, so some form of average costs would need to be developed for use in the model. Reported costs are estimates, not actual construction costs, and they mostly apply to new development. Could be a useful source of cost and effectiveness data for a BMP-specific approach.
LID/GI	"Watershed Nutrient Load Reductions & Stormwater Permitting," EPA Surface Water Branch Meeting Presentation, June 2012	Discusses sources of nitrogen and phosphorus in the Upper Charles River Watershed. Includes construction cost curves to reduce impervious area in Milford, Bellingham, and Franklin. Discusses costs and effectiveness for construction. Is highly area specific. Could be used to model costs for reducing nitrogen and phosphorus loading in areas with similar land cover in the future.
LID/GI	"Sustainable Stormwater Funding Evaluation," Horsley Witten Group, September 2011	Explores BMPs available for Milford, Bellingham, and Franklin to achieve desired phosphorus load reductions and costs associated with each option compared to status quo costs. Describes total area, land use, and impervious area of towns within the Charles River Watershed. Also describes BMP unit costs for different types of land cover. If the 3VS model were expanded to address phosphorus loading in the future, this source could be used to model BMP impacts on phosphorus loadings in areas with land cover data.
LID/GI	"Total Maximum Daily Load for Nutrients In the Lower Charles River Basin," MA DEP, June 2007	Provides Phosphorus TMDL for Lower Charles River compared to existing load by sub-watershed as well as by land cover category. Includes seasonal measures of nitrogen, phosphorus, and chlorophyll a. Could potentially be used to show the impacts of loadings in freshwater ecosystems.
LID/GI	"Urban Stormwater Runoff factsheet," DE Dept. of Natural Resources and Environmental Control	Includes cost data and percent reduction in nutrient loading (N and P) for various BMPs. Could potentially be useful for modeling impacts of specific BMPs in the future.
LID/GI	"Rhode Island State Land Use Policies and Plan," Rhode Island Department of Administration, April 2006	Projections of future land use patterns and descriptions of future land use plans; could be useful for defining future land use trends conditions.

LID/GI	"Capturing Rainwater from Rooftops: An Efficient Water Resource Management Strategy that Increases Supply and Reduces Pollution," NRDC, November 2011	Discusses ways of capturing rooftop rain runoff for use in irrigation or, with some treatment, in commercial applications. Quantifies for a sample of cities the amount of rainwater potentially captured from rooftop systems. Could be used to estimate reduction in runoff from implementing rooftop rain capture if that were a form of LID being considered.
LID/GI	"Research Outcomes on the Efficacy of LID Technologies," UNH Stormwater Center Presentation, March 2011	Presents results of UNH Stormwater research into effectiveness of different LID technologies work. Charts show pollutant removal rate for a variety of pollutants and LID/GI projects. Could be useful for developing a technology-specific approach in future modeling efforts.
LID/GI	"Stormwater Management Strategies for Reduction of N and P Loading to Surface Waters", UNH Stormwater Center, January 2011	Presents data from the UNH Stormwater Center's experiments evaluating the pollutant removal effectiveness of different LID/GI BMPs. Could be useful for developing a technology-specific approach in future modeling efforts.
LID/GI	"Non-Point Source BMP Efficiencies," February 2011	Efficiencies for BMPs by nutrient (N, P, SED) and type (Ag, Resource, Urban). Could be used to model the effectiveness of a wide range of BMPs if a technology-specific approach is pursued in future modeling efforts.
LID/GI	"Historic and Future Phosphorus Loading to the Lower Charles River," EPA Region 1, September 2011	Describes the historic, current, and future trends in phosphorus loadings into the Charles River based on source. Projections are based on planned LID/GI projects which are described in more detail. Could be used to show how implementation of LID/GI reduces phosphorus loadings in future modeling efforts if they address this pollutant. However, would need to further investigate the underlying data to determine whether it could be applied to other watersheds.
LID/GI	"WMOST model documentation," Abt Associates, April 2013	The Watershed Management Optimization Support Tool (WMOST) is a watershed scale model that evaluates the impacts of alternative water resource management options, including LID/GI. It is currently available in a beta version and could provide useful validation of LID impacts. Additional review is necessary to determine if the scale of this model is compatible with the 3VS model.
LID/GI	"GI Benefit in Floodplain Management," Atkins, August 2012	Study measures loss avoidance from the containment of floods using non-specified GI methods. While the study does not describe specific GI projects, the effect of GI on flood control could be extrapolated to other watersheds to determine costs associated with flood damage. In the case of the 3VS model, additional effort would be required to tie flood risk directly to imperviousness, which is the key parameter driven by the use of LID/GI.
LID/GI	"Assessing the Impacts of GI Stormwater BMPS on Stream Communities and Habitats," Naomi Detenbeck, February 2012	Presents results of AED research into impacts of LID/GI BMPs on freshwater ecology at the watershed level. Could be used to show additional environmental benefits of LID/GI, but more work would need to be done to incorporate baseline impairment of freshwater ecosystems and link LID/GI implementation with environmental impacts.

LID/GI	"Fundamentals of Urban Runoff Management: Technical and Institutional Issues," Shaver et al., 2007	Covers many aspects of urban stormwater runoff including impacts to water quality and ecosystems as well as the effectiveness of stormwater management facilities. Chap 3 gives concentrations of various pollutants in urban stormwater, shows variation among several US climatic regions and by land use type. Chap 4 describes relationships between road density and total imperviousness as well as forest cover and total imperviousness, etc. Chap 10 shows removal rates of TSS, P, and N from several different structural facilities based on NJ Stormwater BMP manual. Could be useful in estimating baseline loadings that would be affected by LID/GI.
LID/GI	"Cape Cod Commission Infrastructure Matrix," Cape Cod Commission, October 2012	Describes nutrient management strategies in three main categories: wastewater, fertilizer & impervious surfaces, and water body. Should be particularly useful in developing a 3VS model for Cape Cod.
LID/GI	"The Costs of LID," Stormwater Journal, February 2013	Provides installation cost estimates for BMP on a square foot or gallon basis, as well as annual O&M costs. Describes case studies in different land use types. To the extent that we think costs are similar between Orange County and our study area, these values could be used to model upfront and ongoing costs associated with the described BMPs.
LID/GI	"Triple Bottom Line Assessment of Traditional and GI Options for Controlling CSO Events in Philadelphia's Watersheds," Stratus Consulting, August 2009	For the regions studied, a wide range of benefits are estimated and monetized, including recreational use benefits, residential property value increases, and poverty reduction benefits (from job creation) under different LID scenarios. Benefits are area-specific, and wide ranges are given. We would need additional information about the methodology used in order to apply their results to other areas.
LID/GI	"Scoring Spreadsheet for Recovery Potential Screening in MA", EPA	EPA-developed this screening tool that evaluates water bodies for their potential for restoration. The model connects social and environmental stressors with a wide range of environmental indicators. Could be useful for establishing baseline impairment levels of freshwater ecosystems in order to assess the impacts of LID/GI on such ecosystems.
LID/GI	"Losing Ground: Beyond the Footprint," Mass Audubon, May 2009	Describes development and previous land use patterns in Massachusetts. Includes development rates and levels in MA by municipality. Could be an alternative source of data on projected development trends. For this version of the 3VS model we opted to use ICLUS, which is more easily transferred across different watersheds.
LID/GI	"USDA Natural Resource Conservation Service, Conservation Practices,"	For a wide variety of Conservation BMPs (related to agriculture but some transferable to other land uses) the document describes systems effects qualitatively. Could be used to conceptualize how to apply the 3VS model to characterize LID/GI in rural settings.

EXHIBIT 2-28. SUMMARY OF ADDITIONAL RESEARCH INTO LOW-IMPACT DEVELOPMENT AND GREEN INFRASTRUCTURE: NOT USABLE FOR NARRAGANSETT 3VS

TOPIC	SOURCE	DATA OR INFORMATION DERIVED FROM SOURCE
LID/GI	"Reducing Stormwater Costs through LID Strategies and Practices," EPA Nonpoint Source Control Branch, December 2007	This document presents case studies from various states on LID development, showing costs vs. conventional development. For most sites, several types of costs were considered, including site preparation, stormwater management, paving, and landscaping. Cost savings varied between cases, though LID costs were consistently less than conventional development costs. Extrapolating quantitative estimates from the case studies to the Narragansett Bay watershed would be difficult because costs varied widely depending on the location, even for the same type of project.
LID/GI	"Introductory Webcast on SUSTAIN," EPA, March 2010	Provides an overview of SUSTAIN, a GIS based tool for analyzing stormwater treatment options focusing on GI BMPs. SUSTAIN could potentially be useful as a model input, but it requires a level of data resolution that is more precise than the scale used in the 3VS model.
LID/GI	"Rhode Island Stormwater Design and Installation Standards Manual," Rhode Island Department of Environmental Management/Coast Resources Management Council, December 2010	This document contains technical standards and specifications for the installation of different stormwater management options in RI. It includes guidelines for LID/GI practices in RI but does not contain quantitative estimates of the efficacy of LID/GI practices at a regional scale.
LID/GI	"Planning for Sustainability: A Handbook for Water and Wastewater Utilities," EPA, February 2012	Qualitatively describes plans for sustainably planning and managing wastewater resources and provides examples. Does not contain quantitative data or relationships usable for model development.
LID/GI	"Incorporating GI Approaches into State Stormwater Permits and Programs," EPA Smart Growth Office	Slideshow that focuses on the permitting process, what states can do to encourage GI, and why they should do so. Does not contain quantitative data or relationships usable for model development.
LID/GI	"Storm Water Phase II Annual Program Costs"	RI DEM provided $25,000 to 36 municipalities to develop stormwater management plans. Does not describe the programs or specific BMPs undertaken. Does not contain quantitative data or relationships usable for model development.
LID/GI	"Clean Water Green City", Philadelphia Office of Watersheds	Slideshow making the case qualitatively for Green Infrastructure to deal with stormwater in Philadelphia. Does not contain quantitative data or relationships usable for the 3VS model
LID/GI	"Leveraging Public Spending for Greener Cities", Seattle Department of Planning and Development	Discusses specific areas of Seattle and possible projects. Does not contain quantitative data or relationships usable for model development.
LID/GI	"Green Stormwater Operations and Maintenance Manual", Seattle Public Utilities, August 2009	A pictorial description of various LID/GI projects and how to determine if they're operating optimally. Does not contain quantitative data or relationships usable for model development.

LID/GI	"Seattle Stormwater O&M Maintenance Package", Seattle Public Utilities	Slideshow describing process for O&M of LID/GI projects. Does not contain quantitative data or relationships usable for model development.

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SECTION 3 | MODEL OUTPUTS

3-1. INTRODUCTION

This section presents the results of several scenarios run in the Narragansett 3VS model. These scenarios were designed based on input from stakeholders at RIDEM, and they reflect their priorities with regard to policy interventions and social, environmental, and economic indicators. The scenarios presented in this section include the following policy interventions:

1) **WWTF "Remove Treatment"** – this hypothetical scenario shows what would happen if the wastewater treatment upgrades implemented since 2001 had not taken place.
2) **WWTF "Additional Treatment"** – this scenario models the effects of implementing additional wastewater treatment upgrades at several of the largest facilities in the watershed, beginning in 2025.
3) **ISDS** – this scenario models the effects of upgrading half of the ISDSs in the Narragansett Bay watershed to systems with a removal efficiency of 30 percent, with upgrades occurring between 2014 and 2025.
4) **Aquaculture** – this scenario models the effects of adding aquaculture farms to all bay boxes in the Upper Bay portion of the bay (i.e., boxes 1-10). For each box, the scenario simulates the smaller of (1) enough farms to cover 10 percent of approved aquaculture area, or (2) 100 farms.
5) **LID/GI and Residential Fertilizer** – this scenario groups two interventions together that both address loadings that reach the bay via surface water runoff. The LID/GI component of this scenario involves preventing all projected increases to impervious surface cover and reducing impervious cover by ten percent relative to 2010 levels, beginning in 2014. The residential fertilizer component of the scenario involves reducing the nitrogen content of residential fertilizer by 20 percent, starting in 2014.

For each of the scenarios listed above, we present outputs generated by the model for the following indicators:

1) Average summer monthly nitrogen loadings;
2) Nitrogen concentrations;
3) Change in property values (both from water clarity and from open space);
4) Property tax effect;
5) Change in hypoxia risk;
6) Change in eel grass potential;

7) Change in summer beach visits; and
8) Costs to implement the policy intervention.[9]

The RIDEM stakeholders who requested these scenarios expressed that they were primarily interested in the upper bay portions of Narragansett Bay and its watershed, because that is where efforts to reduce nitrogen loadings and mitigate hypoxia risk are focused. Accordingly, for indicators that are not specific to a particular bay box, we present aggregated impacts for the entire Upper Bay region, defined as either boxes 1-10 (for indicators that are disaggregated at the box level) or all subwatershed areas except for Lower Bay (for indicators that are disaggregated at the subwatershed area level).

The information in this section is not intended to be a comprehensive presentation of the model's capabilities, but rather an illustration of how the model can be used to answer questions posed by a specific group of stakeholders. The model is capable of running a wide variety of scenarios, including variations on the policy interventions discussed in this section (e.g., higher or lower levels of WWTF treatment upgrades), combinations of policy interventions (e.g., aquaculture together with LID/GI), or different policy interventions (e.g., reducing nitrogen loadings from atmospheric deposition, animal waste, or agricultural fertilizer). In addition, scenarios can be designed to reflect adjustments to the default assumptions in the model. For some of the outputs in Section 3-3, we illustrate the impacts of altering assumptions related to future precipitation levels, but other assumptions that could be adjusted include population projections, projections about increases in impervious surface cover, and average nitrogen attenuation rate from groundwater transport of wastewater from ISDSs.

On the other hand, it was not possible to design the model to run all policy scenarios that are of interest to stakeholders. As noted in Exhibit 2-6 (in Section 2-4), we were not able to include all indicators that we originally considered for inclusion, due to constraints related to either data availability or the scope of the Narragansett 3VS model. For example, we were not able to include indicators related to flood risk or loadings of non-nitrogen pollutants (e.g., phosphorus, sediment, pathogens, and metals), so the model cannot show the full range of benefits of any policy intervention that is primarily oriented at affecting these indicators, such as some types of LID/GI. In addition, the model's broad geographic scope prevents it from being able to properly assess certain policy interventions that require a spatially explicit focus, such as waterway engineering.

In Section 3-2, we describe how we defined each of these five scenarios in the model. In Section 3-3, we present model outputs for the scenarios, focusing on the indicators listed above.

3-2. SCENARIO DEFINITIONS

This section describes how we defined the scenarios in the model. For each scenario, we describe how we set parameters to simulate the policy intervention's direct effect on nitrogen loadings as well as parameters to simulate the direct costs of the intervention.

[9] Note that the cost estimates used for these scenarios are meant to be illustrative and are not based on any cost estimates related to any actual proposed policy interventions.

WWTF "REMOVE TREATMENT" SCENARIO

- Category of nitrogen loadings affected: Loadings from WWTFs, specifically the reduction in loadings achieved through implementing treatment upgrades based on NPDES permits issued by RIDEM and MassDEP (both upgrades already implemented and those expected to place over the next few years).
- Approach to modeling impacts on nitrogen loadings: In the baseline, the model includes a time series of per-capita nitrogen loading parameters in each subwatershed area between 2000 and 2018, calibrated so that total nitrogen loadings from each area match the data from the compliance and enforcement monitoring data for the years 2000-2011 and accounting for agreed-upon upgrades set to take place in the years between 2011 and 2018. For this scenario, we adjusted these loading parameters upward to keep per-capita loadings equal to pre-treatment-upgrade levels. Exhibit 3-1 lists the per-capita loadings parameters for 2018, the year after all existing and expected treatment upgrades will be implemented, both for the baseline scenario and for the WWTF remove treatment scenario.
- Approach to modeling costs and other impacts: Because this scenario is meant to be a counter-factual illustration of the environmental impacts that would have resulted had treatment upgrades not been implemented, we did not model costs.

EXHIBIT 3-1. PER-CAPITA NITROGEN LOADINGS PARAMETERS FOR WWTF: BASELINE AND WWTF REMOVE TREATMENT SCENARIO

SUBWATERSHED AREA	WWTF LOADINGS PER CAPITA IN 2018 (KG/PERSON)		PERCENT DIFFERENCE
	BASELINE	REMOVE TREATMENT SCENARIO	
Blackstone Above Manville (RI)	0.33	1.21	263%
Blackstone Above Millville (MA)	0.66	1.05	59%
Pawtuxet	1.53	2.15	40%
Small Watersheds	0.88	1.67	91%
Upper Bay	0.54	2.08	283%
Upper Taunton	1.96	2.30	17%
Mid/Lower Taunton	1.20	1.98	65%

WWTF "ADDITIONAL TREATMENT" SCENARIO

- Category of nitrogen loadings affected: Loadings from seven "large" WWTFs, defined as having loadings greater than 45,000 kg during the summer months in 2014. These facilities, listed in Exhibit 3-2, account for roughly 70 percent of total summer WWTF loadings and would likely be targeted for any additional treatment upgrades.

  Approach to modeling impact on nitrogen loadings: We assume that sufficient treatment upgrades would be applied at these seven facilities to achieve an effluent concentration of 3.0 mg/L. Exhibit 3-2 shows the baseline effluent concentrations at each facility (based on either the most recent compliance and enforcement monitoring data or treatment upgrades expected to be in place by 2015), the target concentrations, and the percent reduction in loading concentrations required to reach the target. For each subwatershed area with "large" WWTFs, we reduced the per-capita loading parameters by the weighted average percent reduction of all "large" WWTFs within the subwatershed area (weighted by summer nitrogen loadings at each facility). Of the seven subwatershed areas (excluding Lower Bay), we reduced loadings at four for this scenario: Blackstone Above Millville, Small Watersheds, Upper Taunton, and Upper Bay.

EXHIBIT 3-2. PERCENT REDUCTIONS IN NITROGEN LOADINGS MODELED IN THE WWTF ADDITIONAL TREATMENT SCENARIO

WWTF	LATEST AVAILABLE N CONC. (MG/L)	TARGET 2025 N CONC. (MG/L)	PERCENT REDUCTION	PERCENT REDUCTION FOR ALL WWTF LOADINGS BY SUBWATERSHED AREA
Worcester/UBWPAD	4.6[1]	3.0	35%	Blackstone Above Millville: 28%
Bucklin	5.0[2]	3.0	40%	Small Watersheds: 25%
Brockton	3.2[1]	3.0	7%	Upper Taunton: 3%
Fall River	17.6[1]	3.0	83%	Upper Bay: 66%
Bristol	26.1[1]	3.0	89%	
Cranston	8.0[3]	3.0	63%	
Fields Point	5.0[4]	3.0	40%	

Notes:
1. Average monthly concentrations in May through October, 2011, as reported in MA and RI compliance and enforcement monitoring data.
2. Targeted permit limit expected to be met in 2014.
3. Targeted permit limit expected to be met in 2015.
4. Targeted permit limit expected to be met in 2013.

- Approach to modeling costs and other impacts: For this scenario, we modeled costs using the financing module. We assumed that total capital costs for all treatment upgrades would be $1.0 billion. We developed this estimate by extrapolating from the estimated cost of $232 million required for treatment upgrades to comply with permit limits of 5.0 mg/L at the Upper Blackstone, Bucklin, and Fields Point facilities.[10] Additional assumptions used to estimate financing for this scenario are as follows:
    - Financing period: 2022-2051 (though treatment upgrades are not fully implemented until 2025).

[10] NBC Presentation from Snapshot of the Bay 2011 (for Bucklin and Fields point costs) Upper Blackstone Plant Improvement Project. Tom Walsh. Upper Blackstone Water Pollution Abatement District. (for Upper Blackstone costs).

    - Interest rate: five percent.
    - Social discount rate (for net present value estimates): zero percent.

- To estimate per capita costs for this scenario, we divided total costs over the projected sewered population in the four subwatershed areas with large WWTFs, averaged over 2022 to 2050, which we estimate to be 1.2 million people. For reference, the model's initial values for the sewered population in these four subwatershed areas are as follows:
    - Blackstone Above Millville: 241,000;
    - Small Watersheds: 191,000;
    - Upper Bay: 457,000; and
    - Upper Taunton: 158,000.

ISDS SCENARIO

- Category of nitrogen loadings affected: Nitrogen loadings from ISDSs, or unsewered wastewater, reaching Narragansett Bay (i.e., septic systems and cesspools in areas with soils with high filtration rates (sand, sandy loam, or silt loam) that are connected to the bay or within 10 meters of rivers and streams.
- Approach to modeling impact on nitrogen loadings: For this scenario, we assumed that 50 percent of ISDSs that are not already upgraded (i.e., ISDSs installed prior to 2002) would be upgraded to have a nitrogen removal efficiency of 30 percent. With the model's baseline assumption of ten percent removal of nitrogen from groundwater attenuation, this upgrade would result in 63 percent of nitrogen loadings from upgraded ISDSs (90 percent * 70 percent) reaching Narragansett Bay. We assume that the upgrade process would take place gradually between 2014 and 2025.
- Approach to modeling costs and other impacts: The model includes a default cost per upgraded ISDS of $10,000. Because this scenario assumes a high degree of nitrogen removal efficiency, we used an upgrade cost of $25,000 per system instead (A. Liberti, Personal Communication on August 4, 2014). We use the model's financing module to model costs for this scenario, assuming a 30-year loan (starting in 2014) with a five percent interest rate (and no social discount rate).
- To calculate costs per capita, we divide the total cost of upgrading ISDSs by one half of the average unsewered population between 2014 and 2050, which we estimate to be about 720,000 people. Note that because the ISDS intervention only targets households with ISDSs installed before 2002, this number likely overestimates the population affected, resulting in an underestimate of per capita costs.

AQUACULTURE SCENARIO

- Category of nitrogen loadings affected: This scenario does not affect any particular category of nitrogen loadings entering Narragansett Bay. Rather, it reflects the removal of nitrogen from the bay by oyster aquaculture farms.
- Approach to modeling impact on nitrogen loadings: As noted in Section 2-8, the model includes data on the total area in each bay box approved for oyster shellfishing. For this scenario, we

assume that 10 percent of the approved area in each box is developed with oyster farms, with a maximum of 100 one-acre oyster farms per box. The number of farms modeled in each bay box is listed in Exhibit 3-3. Given that there are currently three aquaculture farms in boxes 1-10 of Narragansett Bay (D. Beutel, Personal communication on November 5, 2014), this scenario represents an extreme high end estimate of the potential impact of using oyster aquaculture to remove nitrogen.

- Approach to modeling costs and other impacts: This scenario uses the default cost assumptions for oyster aquaculture included in the model, namely that each farm would have annual operating costs of $10,000. The model also assumes that each farm would employ two people and have annual revenues of $57,000.

EXHIBIT 3-3. OYSTER FARMS PER BOX IN THE AQUACULTURE SCENARIO

BAY BOX	BOX NAME	PERMITTED SHELLFISH AREA (ACRES)	NUMBER OF NEW FARMS
1	Providence River Estuary - North of Fields Point	0	0
2	Providence River Estuary - South of Fields Point	0	0
3	Upper Bay North	0	0
4	Upper Bay West	381	38
5	Upper Bay East	0	0
6&7	Greenwich Bay	241	24
8	Upper West Passage	7,851	100
9	Upper East Passage	5,408	100
10	Mount Hope Bay	0	0

LID/GI AND FERTILIZER SCENARIO

- Category of nitrogen loadings affected: Loadings from surface water runoff on developed land (LID/GI), particularly loadings from residential fertilizer.
- Approach to modeling impact on nitrogen loadings: This scenario simulates two policy interventions applied together: LID/GI and residential fertilizer reductions. For the LID/GI component, we set impervious cover in all watersheds to levels 10 percent lower than 2010 levels. This reduction in impervious cover is gradually implemented between 2014 and 2020, after which point impervious cover levels are held constant for all subsequent years. For the residential fertilizer component, we decrease nitrogen loadings from residential fertilizer by 20 percent, starting in 2014.
- Approach to modeling costs and other impacts: We use the model's default cost assumptions for LID/GI, namely that LID/GI on new development has no cost and that LID/GI retrofits (i.e., any LID/GI that results in a decrease of impervious cover) has an increasing cost per acre of imperviousness reduced. We note that the default cost assumptions in the model are rough estimates that rely on costs from stormwater utilities as a proxy of the actual annualized costs of retrofitting traditional development to reduce effective imperviousness. For the residential

fertilizer component, we assume that nitrogen reductions cost $50 per kilogram of nitrogen reduced per year.

- Because these interventions apply to the entire watershed, we estimate per-capita costs by dividing total annualized costs by the total population of the watershed.
- For the property value impacts of increased open space, we use the default assumptions in the model, namely using the ICLUS projections for increased housing density, setting the percent of LID/GI that involves increased open space around new units to 100 percent, setting the maximum area surrounding new units that can be turned into new open space to 10 percent, and setting the percent of existing units that have new open space within a 500-meter radius to 100 percent.

3-3. SCENARIO OUTPUTS

In this section we present the model's outputs for selected indicators for each of the scenarios described above. We first discuss impacts on summer nitrogen loadings and concentrations, followed by impacts on social and economic indicators. To illustrate the model's capabilities, we present detailed graphs for the two WWTF scenarios, as well as a table summarizing the primary outputs of each scenario across a range of environmental, social, and economic indicators. For the other three scenarios, the discussion in this section is limited to graphs of nitrogen loadings and a summary table of impacts on other indicators.

WWTF "REMOVE TREATMENT" AND "ADDITIONAL TREATMENT" SCENARIOS

To facilitate comparison across the two scenarios dealing with loadings from WWTFs, we present the results of these two scenarios together. For these scenarios, we first present a series of graphs illustrating impacts on nitrogen loadings and concentrations, property value impacts, property tax impacts, changes in hypoxia risk and eel grass recovery potential, and beach visits. We then discuss cost impacts before presenting an overall summary of impacts across several environmental, economic, and social indicators.

Nitrogen Loadings

Exhibit 3-4 presents average summer monthly nitrogen loadings from all wastewater facilities to the upper bay region of Narragansett Bay for the baseline scenario as well as for both WWTF scenarios. As the exhibit shows, under the "remove treatment scenario, nitrogen loadings are roughly 200,000 kg per month above the baseline from 2014 onward, and under the "additional treatment scenario, nitrogen loadings are roughly 86,000 kg/month below baseline from 2025 onward. This suggests that a reduction of effluent nitrogen concentrations to 3.0 mg/L at wastewater treatment facilities with the highest nitrogen loadings would achieve a reduction in loadings of roughly 40 percent of that achieved by treatment upgrades implemented or agreed to between 2002 and 2018 under the baseline.

EXHIBIT 3-4. AVERAGE SUMMER MONTHLY WWTF LOADINGS TO UPPER BAY IN THE BASELINE AND WWTF SCENARIOS

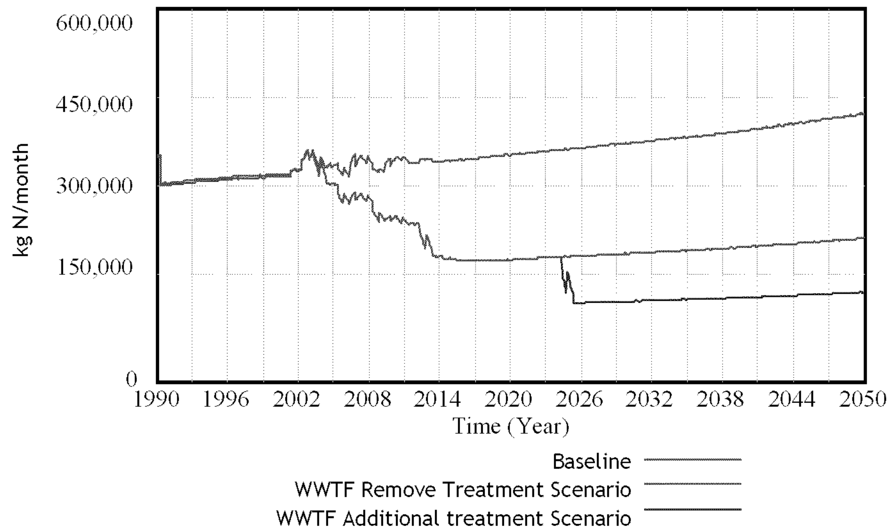
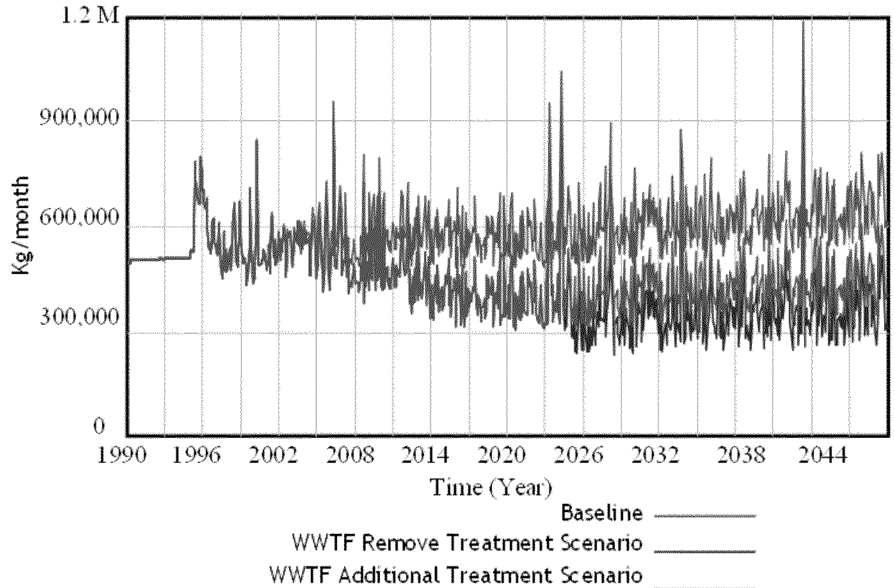


Exhibit 3-5 presents the average summer monthly loadings from all source categories to the upper bay. Note that the fluctuations in loadings depicted in the graph are the result of variation in monthly precipitation, with the high points, or "spikes" representing extreme precipitation events. As the exhibit shows, the relative impact of the WWTF interventions is somewhat smaller when all source categories are taken into account. In addition, neither WWTF scenario affects the variability of loadings or the sensitivity of loadings to spikes in precipitation.

EXHIBIT 3-5. AVERAGE SUMMER MONTHLY LOADINGS (ALL SOURCE CATEGORIES) TO UPPER BAY IN THE BASELINE AND WWTF SCENARIOS



Nitrogen Concentrations

To illustrate the nitrogen circulation functionality in the model, Exhibits 3-6, 3-7, and 3-8 present the impacts of the WWTF scenarios on nitrogen concentrations in three bay boxes: Providence River Estuary North of Fields Point (Box 1), Greenwich Bay (Boxes 6 and 7), and Mt. Hope Bay (Box 10), respectively. As shown in Exhibit 2-16, the majority of wastewater treatment facilities in the Narragansett Bay watershed discharge into Boxes 1 or 10, with only the East Greenwich facility discharging into Greenwich Bay. However, as Exhibit 3-7 shows, the model is able to show how changes in nitrogen loadings elsewhere in the bay have an effect on nitrogen concentrations in Greenwich Bay. In Exhibit 3-8, it is clear that removing recent treatment upgrades has a sizable impact on the nitrogen concentrations in Mt. Hope Bay. On the other hand, because most of the "large" WWTFs targeted in the "additional treatment" scenario do not discharge into Mt. Hope Bay (and the model only simulates flow of nitrogen from Mt. Hope Bay into other regions of the bay), this scenario shows a minimal impact on concentrations in this region of the bay.

EXHIBIT 3-6. NITROGEN CONCENTRATIONS IN PROVIDENCE RIVER ESTUARY NORTH OF FIELDS POINT (BOX 1) IN THE BASELINE AND WWTF SCENARIOS

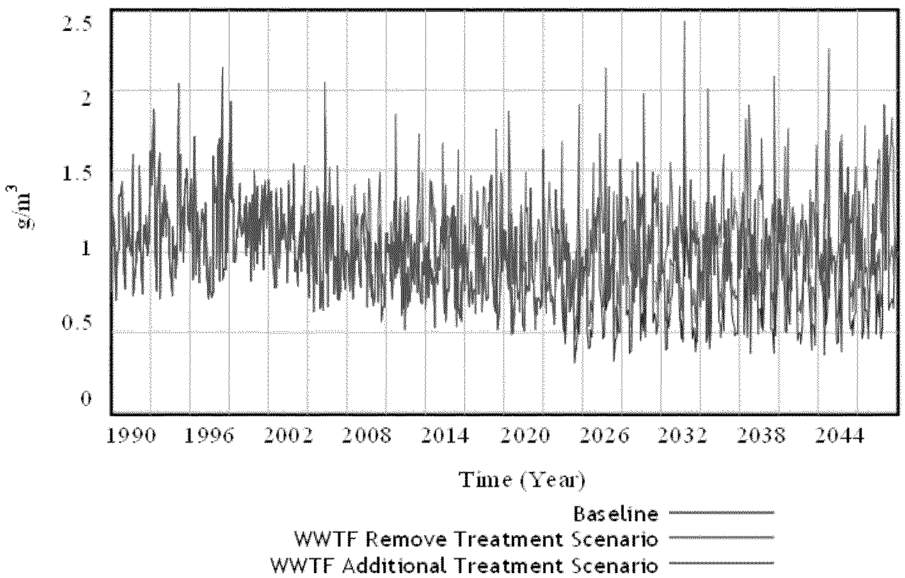


EXHIBIT 3-7. NITROGEN CONCENTRATIONS IN GREENWICH BAY (BOXES 6&7) IN THE BASELINE AND WWTF SCENARIOS

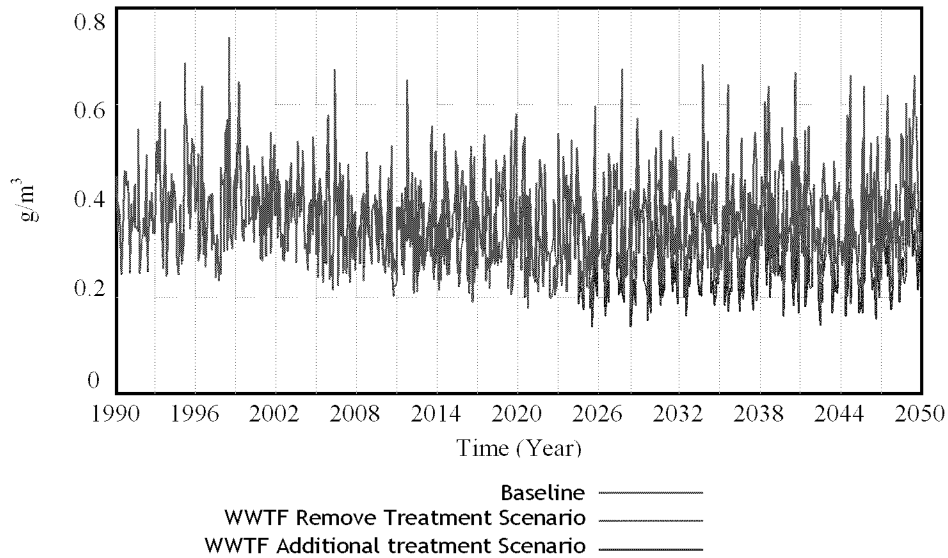
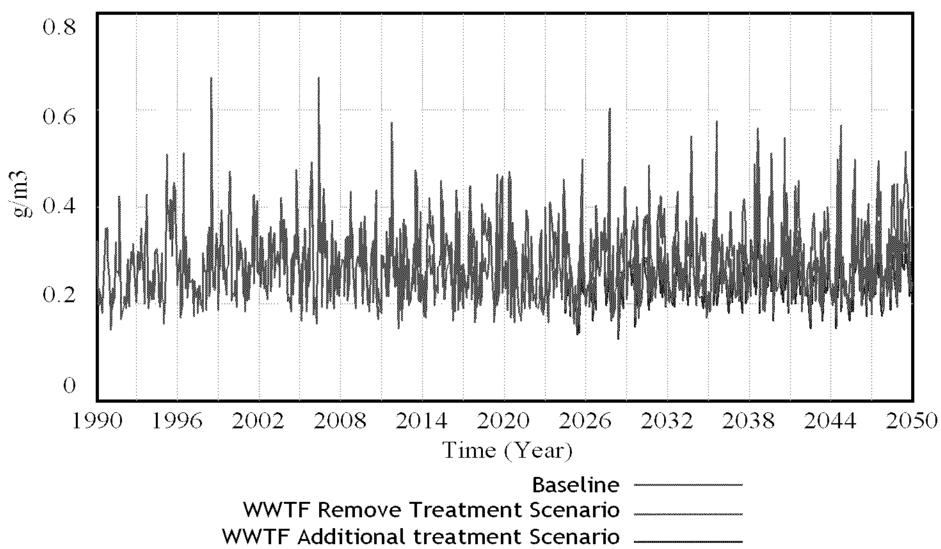


EXHIBIT 3-8. NITROGEN CONCENTRATIONS IN MT. HOPE BAY (BOX 10) IN THE BASELINE AND WWTF SCENARIOS



Property Value and Tax Impacts

Exhibit 3-9 shows the impact of water clarity on upper bay coastal property values over time in the two WWTF scenarios, relative to the baseline scenario. The exhibit suggests that existing and planned treatment upgrades prevented a loss in coastal property value of about $300 million, while further treatment could add about $150 million to coastal properties in the upper bay. We estimate that coastal properties in the upper bay have a total value of about $23 billion as of 2014, meaning that these impacts represent a loss of 1.3 percent and a gain of 0.6 percent of total value, respectively.

EXHIBIT 3-9. PROPERTY VALUE IMPACT DUE TO CHANGES IN WATER CLARITY IN WWTF SCENARIOS

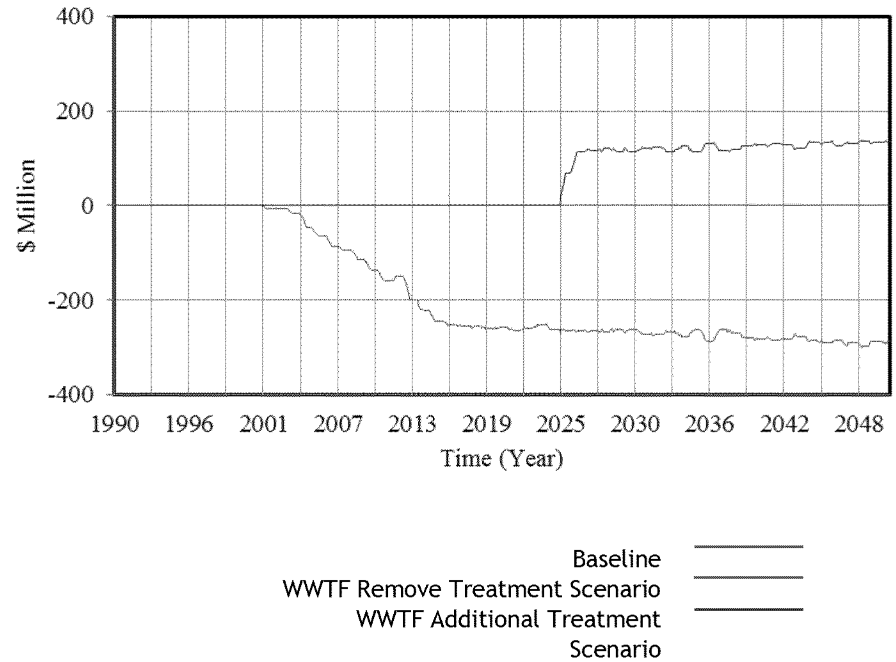
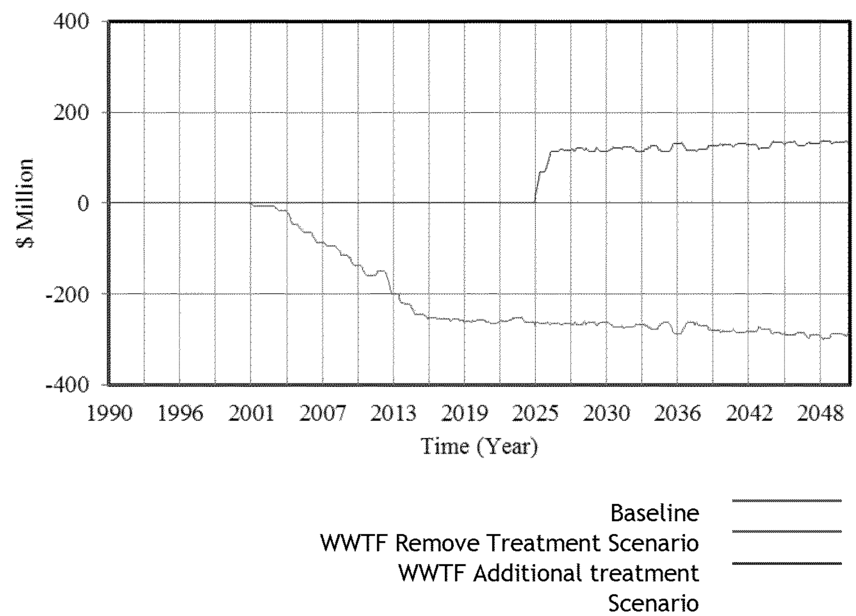


Exhibit 3-10 shows the cumulative property tax impact over time for each WWTF scenario, relative to the baseline scenario. Changes in water clarity in the "additional treatment" scenario are projected to increase total property tax receipts by about $47 million between 2025 and 2050, while removing the treatment upgrades already implemented (and agreed upon) would decrease property tax receipts by about $166 million between 2005 and 2050.

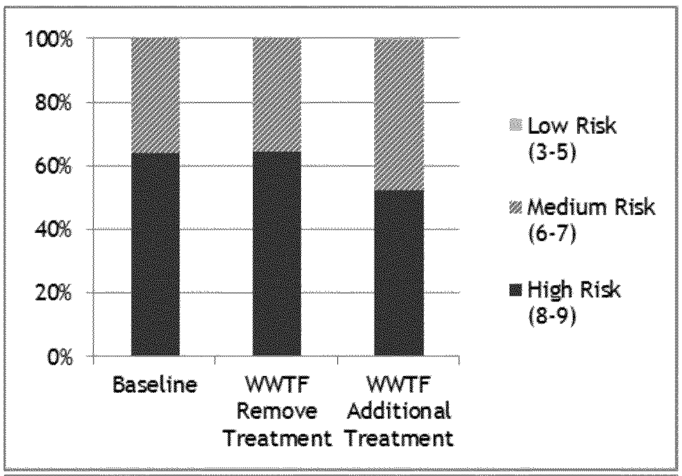
EXHIBIT 3-10. PROPERTY TAX IMPACT DUE TO CHANGES IN WATER CLARITY IN WWTF SCENARIOS



Hypoxia Risk and Eelgrass Recovery Potential Indexes

Exhibit 3-11 shows the frequency of the three categories of hypoxia risk index from 2014 to 2050 for the baseline and two WWTF scenarios. Note that the hypoxia risk index is calculated in the model by summing three qualitative indices that each have values ranging from one to three: chlorophyll A, location in the bay, and precipitation (as described in Section 2-9). Of these indices, only chlorophyll A is affected by changes in nitrogen loadings. The top graph in the exhibit shows how hypoxia risk changes in Providence River Estuary North of Fields Point (Box 1), while the bottom graph illustrates changes in hypoxia risk in Greenwich Bay (Boxes 6 and 7). Comparison of the model results for the baseline and the "remove treatment" scenario in the top graph suggests that recent treatment upgrades – while significantly reducing nitrogen concentrations in this region of the bay – did not make a measurable impact in hypoxia risk. Additional targeted treatment at several of the facilities discharging into Box 1, however, appears to reduce the frequency of the highest hypoxia risk category in this region of the bay from 64 percent to 52 percent. The bottom graph shows that existing and planned treatment upgrades have made a significant impact on hypoxia risk in Greenwich Bay, increasing the frequency of the lowest risk category from 18 percent to 35 percent. Additional treatment does not appear likely to increase the frequency of low hypoxia risk, but it does appear to decrease the frequency of high hypoxia risk from 30 percent to 18 percent.

EXHIBIT 3-11. FREQUENCY OF HYPOXIA RISK INDEX SCORES FOR THE BASELINE AND WWTF SCENARIOS, 2014-2050: PROVIDENCE RIVER ESTUARY NORTH OF FIELDS POINT (TOP GRAPH) AND GREENWICH BAY (BOTTOM GRAPH)



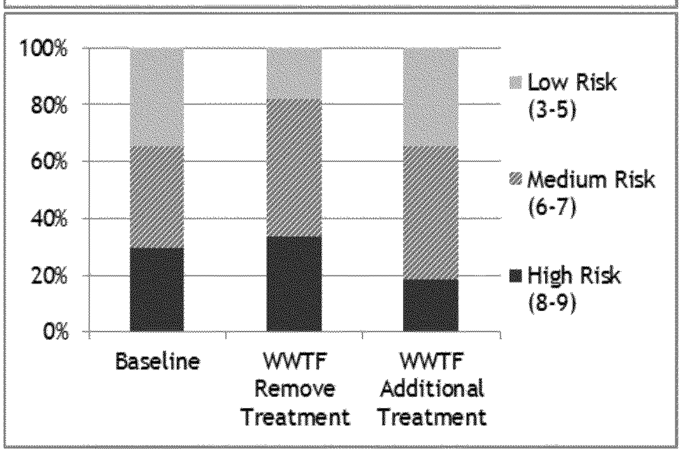


Exhibit 3-12 shows the frequency of the three categories of the eelgrass potential index for the baseline and two WWTF scenarios. Note that the model calculates this index by multiplying two qualitative indices (as described in Section 2-9, each with values ranging from one to three: relative area of eelgrass transplant suitability and water clarity (measured by Secchi depth). Of these two indices, only water clarity is affected by changes in nitrogen loadings. Again, the top graph shows values for Providence River Estuary North of Fields Point, while the bottom graph shows values for Greenwich Bay. The top graph shows that removing treatment upgrades at WWTFs has relatively little impact on eel grass recovery in Box 1; additional treatment upgrades at large facilities significantly increases the frequency of the medium potential index value, but even with these upgrades, this region of the bay has the lowest potential for eelgrass recovery about 84 percent of the time between 2014 and 2050. On the other hand, the bottom graph shows no difference in eelgrass recovery potential between the baseline and "additional treatment" scenarios. Moreover, even without recent and planned treatment upgrades, Greenwich Bay has a high eelgrass recovery potential about 98 percent of the time between 2014 and 2050, so there is little room for improvement for this particular indicator. Note also that Greenwich Bay always has at least medium potential for eelgrass recovery in the model, due to its high relative area of eelgrass transplant suitability (see Exhibits 2-18 and 2-19).

For both the hypoxia risk and eelgrass recovery potential indices, we present results here in terms of the frequency of each of the three categories: high, medium, and low. This is because the indices, as defined in the model, are best interpreted in terms of these three categories. It is also possible to compare scenarios in terms of average index values over time, in order to identify changes in index values that do not cause shifts from one category to another. For example, Greenwich Bay has an average eel grass recovery potential value of 8.9 between 2014 and 2050 in the baseline scenario, vs. 8.1 in the "remove treatment" scenario (a decrease of nine percent) and 9.0 in the "additional treatment" scenario (an increase of 0.4 percent).

Beach Visits

Exhibit 3-13 shows summer monthly beach visits in Greenwich Bay under the baseline and WWTF scenarios. Each dot in the graph represents the number of visitors to Greenwich Bay beaches during a summer month. As the exhibit shows, in the "Remove Treatment" scenario, there are many months after 2010 where the number of beach visitors is projected to be below 70,000. Conversely, in the "Additional Treatment" scenario, projected monthly beach visits rarely fall below 80,000.

EXHIBIT 3-12. FREQUENCY OF EELGRASS POTENTIAL INDEX SCORES FOR THE BASELINE AND WWTF SCENARIOS, 2014-2050: PROVIDENCE RIVER ESTUARY NORTH OF FIELDS POINT (TOP GRAPH) AND GREENWICH BAY (BOTTOM GRAPH)

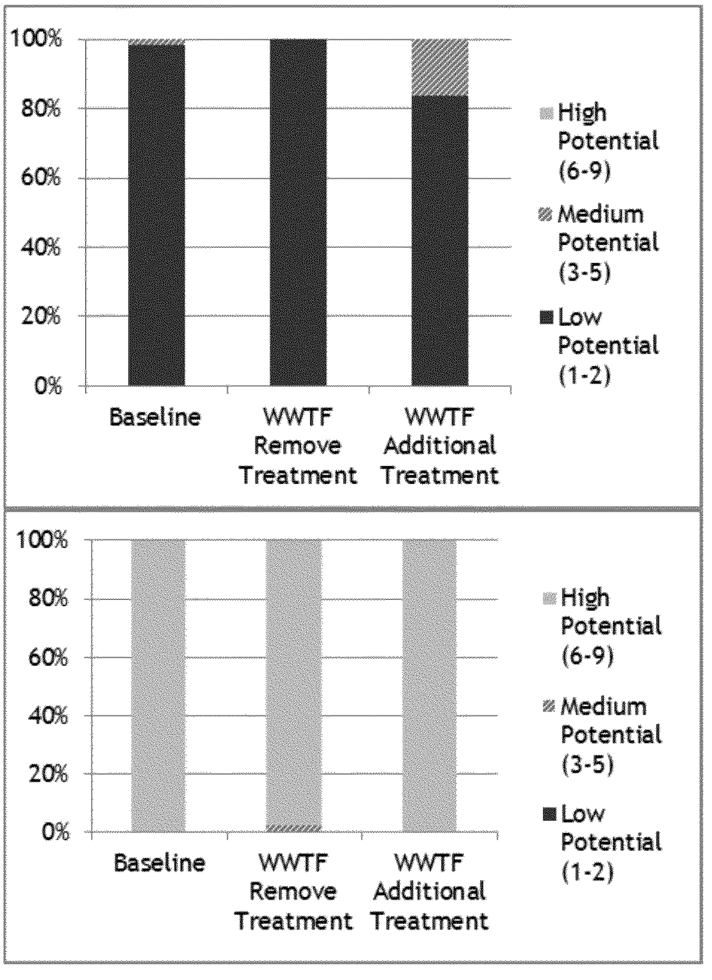
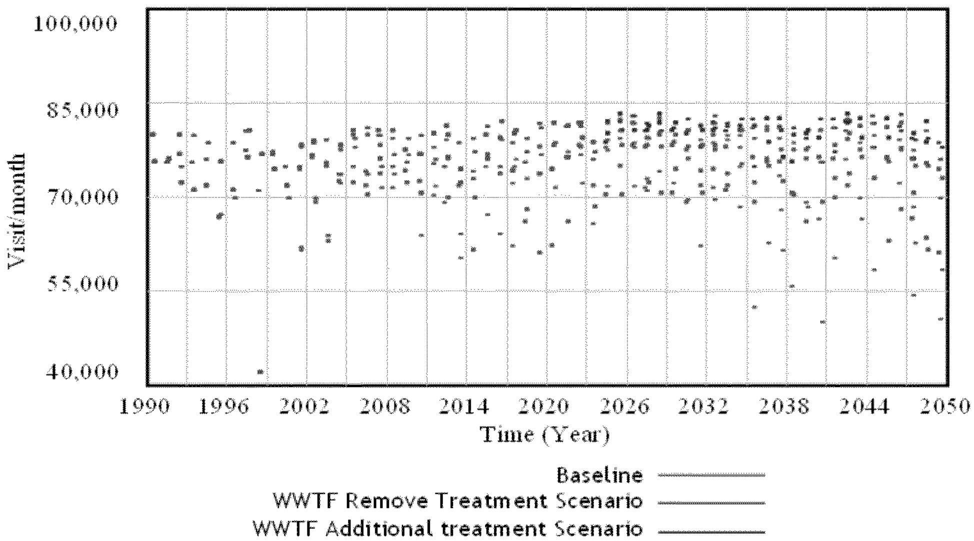


EXHIBIT 3-13. SUMMER MONTHLY BEACH VISITS IN THE BASELINE AND WWTF SCENARIOS, GREENWICH BAY



Costs

Using the assumptions described in Section 3-2, the model estimates that the total costs of financing additional upgrades at seven WWTFs with the largest nitrogen loadings would be \$1.9 billion, including interest payments costs. Through financing, this amount would be paid off over 30 years at a cost of \$65 million per year. Dividing this cost by the average size of the sewered population in the Blackstone Above Millville, Small Watersheds, Upper Bay, and Taunton Above Bridgewater subwatershed areas over the modeled timeframe (1.2 million people) yields an estimate of per capita annual costs of \$55.

Summary

Exhibit 3-14 summarizes model's outputs for selected environmental, social, and economic indicators for the two WWTF scenarios discussed in this section. The values in the tables represent differences between each scenario and the baseline. For most indicators, the table presents aggregate values for the upper bay region (Boxes 1-10), but for indicators that are box-specific, the table presents results for Providence River Estuary North of Fields Point (Box 1), or Greenwich Bay (Boxes 6 and 7). To illustrate the maximum impact for each scenario, the exhibit displays values for 2050, the last year represented in the 3VS model.

EXHIBIT 3-14. SUMMARY OF ENVIRONMENTAL, SOCIAL, AND ECONOMIC INDICATORS FOR THE TWO WWTF SCENARIOS IN 2050

INDICATOR[1]	MODEL OUTPUTS BY SCENARIO (ALL VALUES ARE DIFFERENCES RELATIVE TO BASELINE VALUES)	
	WWTF "REMOVE TREATMENT"	WWTF "ADDITIONAL TREATMENT"
Summer Monthly N Loadings	200,000 kg/month	-86,000 kg/month
Summer N Concentration at Providence River Estuary North of Fields Point (Box 1)	0.64 mg/L	-0.28 mg/L
Change in Property Value due to Water Clarity	-$290 million	$130 million
Cumulative Property Tax Impact	-$170 million	$47 million
Change in Summer Beach Visits	-42,000 visits	13,000 visits
Frequency of High Hypoxia Risk (2014-2050)		
Providence River Estuary North of Fields Point (Box 1)	0.4%	-12%
Greenwich Bay (Boxes 6&7)	4.0%	-11%
Frequency of Medium Eel Grass Potential (2014-2050)		
Providence River Estuary North of Fields Point (Box 1)	-1.6%	15%
Greenwich Bay (Boxes 6&7)	2.3%	No change
Annual per Capita Cost	Not Modeled	$55/person/year

Notes:
1. Unless otherwise indicated, values presented for each indicator are for the entire upper bay region.

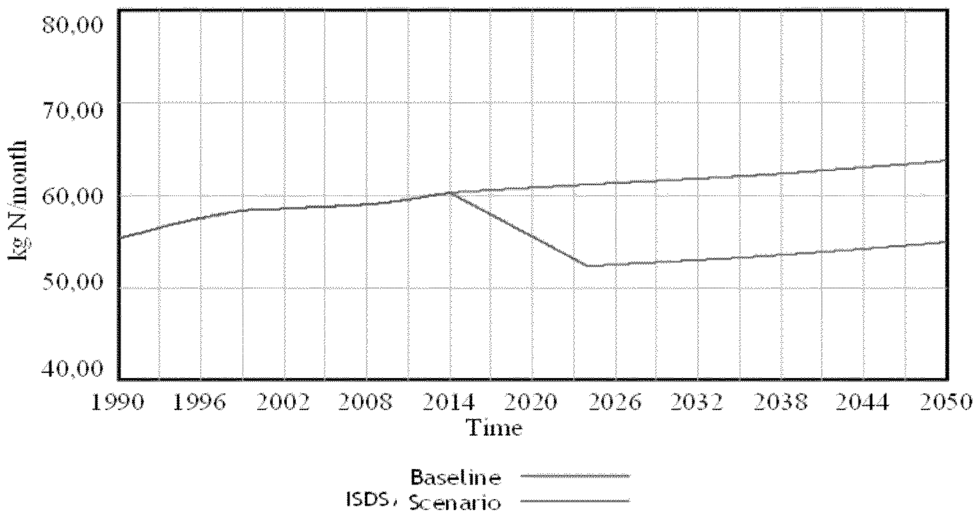
ISDS SCENARIO

For the ISDS scenario we first present the impacts on average summer monthly loadings over time. We then briefly discuss cost estimates and present a summary table comparing the maximum impacts of the ISDS scenario to the WWTF "additional treatment" scenario.

Nitrogen Loadings

Exhibit 3-15 shows ISDS loadings in the baseline and ISDS scenario. The exhibit shows that upgrading all ISDSs in the watershed to a 30 percent nitrogen removal efficiency results in a reduction in average summer nitrogen loadings of about 10,000 kg. Though this represents a significant portion of overall loadings from ISDSs, it is a relatively insignificant portion of total loadings from the watershed.

EXHIBIT 3-15. AVERAGE SUMMER MONTHLY NITROGEN LOADINGS FROM ISDSS TO THE UPPER BAY



Costs

Using the assumptions described in Section 3-2, the model estimates that the total costs of financing upgrades of nearly 50,000 ISDSs throughout the Narragansett Bay watershed would be about $2.4 billion, which works out to about $79 million per year. Dividing this value by the affected population (approximately 720,000 people) yields an estimated annual cost of about $220 per person per year.

Summary

Exhibit 3-16 compares the results of the ISDS scenario to the WWTF "additional treatment" scenario, showing model outputs for several environmental, social, and economic indicators in the year 2050. Once again, the values in the tables represent differences between each scenario and the baseline. Compared to additional WWT treatment, the model estimates that upgrading ISDSs would have fewer beneficial impacts (i.e., less reduction in nitrogen loadings and concentrations, less improvement in property values and taxes, less increase in monthly beach visits, and less of an improvement in hypoxia risk and eel grass recovery potential) but higher per capita annual costs.

EXHIBIT 3-16. SUMMARY OF ENVIRONMENTAL, SOCIAL, AND ECONOMIC INDICATORS FOR THE ISDS SCENARIO AND THE WWTF "ADDITIONAL TREATMENT" SCENARIO IN 2050

INDICATOR[1]	MODEL OUTPUTS BY SCENARIO (ALL VALUES ARE DIFFERENCES RELATIVE TO BASELINE VALUES)	
	ISDS UPGRADES	WWTF "ADDITIONAL TREATMENT"
Summer Monthly N Loadings	-8,800 kg/month	-86,000 kg/month
Summer N Concentration at Providence River Estuary North of Fields Point (Box 1)	-0.02 mg/L	-0.28 mg/L
Change in Property Value due to Water Clarity	$14 million	$130 million
Cumulative Property Tax Impact	$6.4 million	$47 million
Change in Summer Beach Visits	1,700 visits	13,000 visits
Frequency of High Hypoxia Risk (2014-2050)		
Providence River Estuary North of Fields Point (Box 1)	0%	-12%
Greenwich Bay (Boxes 6&7)	-1.8%	-11%
Frequency of Medium Eel Grass Potential (2014-2050)		
Providence River Estuary North of Fields Point (Box 1)	0.2%	15%
Greenwich Bay (Boxes 6&7)	No change	No change
Annual per Capita Cost (for 30-year financing period)	$219/person/year	$55/person/year

Notes:
1. Unless otherwise indicated, values presented for each indicator are for the entire upper bay region.

AQUACULTURE SCENARIO

For the aquaculture scenario we first present the impacts of adding aquaculture farms on annual nitrogen loadings over time in two of the areas of the bay where new aquaculture farms are modeled. We then briefly discuss cost estimates and present a summary table comparing the maximum impacts of the aquaculture scenario to the WWTF "additional treatment" scenario.

Nitrogen Loadings

Exhibits 3-17 and 3-18 show the impact of the aquaculture scenario on annual nitrogen loadings in two of the areas where the scenario simulates the development of oyster farms: Exhibit 3-17 shows loadings to Upper Bay West (Box 4), while Exhibit 3-18 shows loadings to Greenwich Bay (Box 6). Note that the model does not currently have the capability to show summer monthly loadings by box, which is why these exhibits present annual loadings for these two bay boxes. Exhibit 3-17 shows that the addition of 38 one-acre farms to Upper Bay West (Box 4) causes a significant decrease in the net flow of nitrogen into this region of the bay. Annual loadings for this region are not particularly high in the baseline, and in the aquaculture scenario, net annual loadings fall below zero in some time periods, meaning that oyster aquaculture is removing more nitrogen than is being added to this region of the bay from the watershed and from atmospheric deposition. By 2050, annual nitrogen loadings are about 11,000 lower in the aquaculture scenario than in the baseline, representing a decrease of over 80 percent. In Greenwich Bay, as shown in Exhibit 3-18, the absolute and relative effects of the aquaculture scenario on annual loadings are both smaller, with a decrease in 2050 loadings of about 7,200 kg, or 27 percent of baseline loadings.

EXHIBIT 3-17. TOTAL ANNUAL NITROGEN LOADINGS TO UPPER BAY WEST (BOX 4) IN THE BASELINE AND AQUACULTURE SCENARIOS

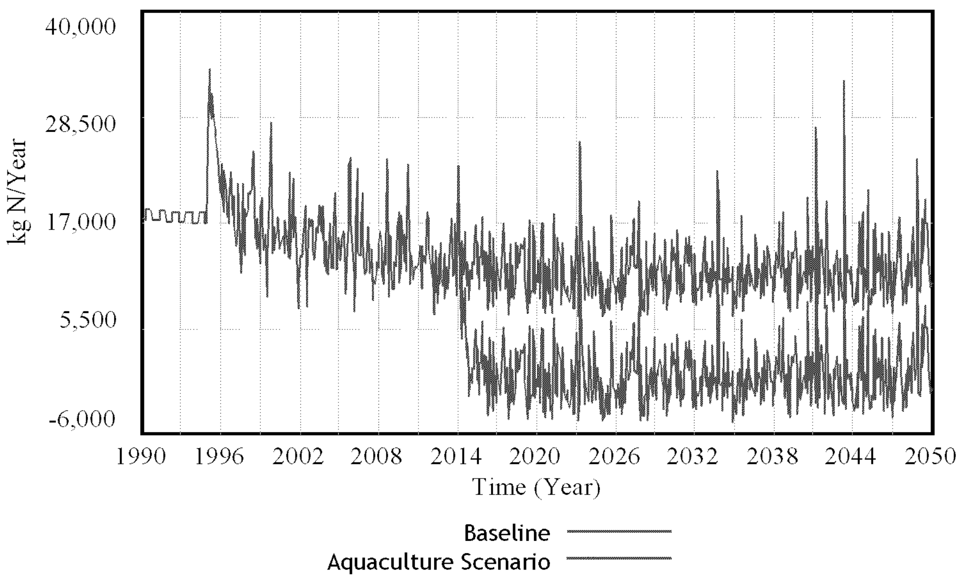
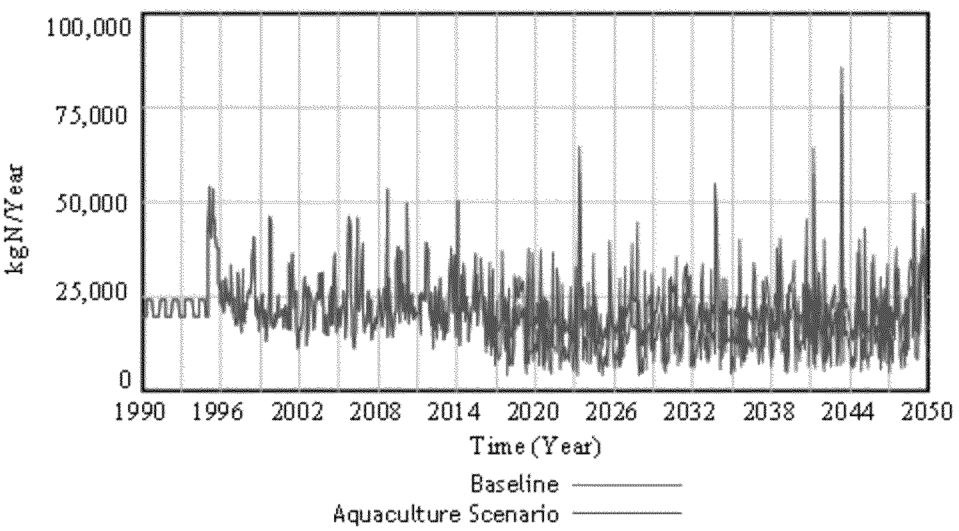


EXHIBIT 3-18. TOTAL ANNUAL NITROGEN LOADINGS TO GREENWICH BAY (BOXES 6&7) IN THE BASELINE AND AQUACULTURE SCENARIOS



Costs

Using the model's default cost and revenue assumptions (described in Section 3-2), aquaculture farms in this scenario incur annual operating costs of $2.6 million, while generating annual revenues of $15 million and employing about 520 people.

Summary

Exhibit 3-19 compares the results of the aquaculture scenario to the WWTF "additional treatment" scenario, showing model outputs for several environmental, social, and economic indicators in the year 2050. Because the aquaculture scenario does not affect Providence River Estuary North of Fields Point (Box 1), the table presents results for Greenwich Bay (Boxes 6 and 7) and Upper West Passage (Box 8) instead. As the table shows, even if the model uses an extreme high end estimate of the number of new aquaculture farms that could be added to the bay, the overall impacts on nitrogen loadings and other indicators are much smaller than the impacts seen under the WWTF "additional treatment" scenario. At the local level, however, there may be advantages to implementing oyster aquaculture in some areas, especially when considering potential revenue and job creation benefits.

EXHIBIT 3-19. SUMMARY OF ENVIRONMENTAL, SOCIAL, AND ECONOMIC INDICATORS FOR THE AQUACULTURE SCENARIO AND THE WWTF "ADDITIONAL TREATMENT" SCENARIO IN 2050

INDICATOR[1]	MODEL OUTPUTS BY SCENARIO (ALL VALUES ARE DIFFERENCES RELATIVE TO BASELINE VALUES)	
	AQUACULTURE	WWTF "ADDITIONAL TREATMENT"
Summer Monthly N Loadings	-6,600 kg/month	-86,000 kg/month (5,500 kg/month in Boxes 4, 6&7, 8, and 9)
Summer N Concentration at Greenwich Bay (Boxes 6&7)	-0.01 mg/L	-0.07 mg/L
Summer N Concentration at Upper West Passage (Box 8)	-0.01 mg/L	-0.05 mg/L
Change in Property Value due to Water Clarity	$2.3 million	$130 million
Cumulative Property Tax Impact	$1.1 million	$47 million
Change in Summer Beach Visits	1,900 visits	13,000 visits
Frequency of High Hypoxia Risk at Greenwich Bay (Boxes 6&7) (2014-2050)	-1.8%	-11%
Frequency of High Hypoxia Risk at Upper West Passage (Box 8) (2014-2050)	No change	No change
Frequency of Medium Eel Grass Potential at Greenwich Bay (Boxes 6&7) (2014-2050)	No change	No change
Frequency of Medium Eel Grass Potential at Upper West Passage (Boxes 8) (2014-2050)	No change	No change
Annual per Capita Cost (for 30-year financing period)	No cost to the public	$55/person/year

Notes:
1. Unless otherwise indicated, values presented for each indicator are for the entire upper bay region.

LID/GI AND FERTILIZER SCENARIOS

For the LID/GI and fertilizer scenario, we first present the impacts on average summer monthly loadings over time, under both default precipitation assumptions and alternate "high precipitation" assumptions. We then briefly discuss cost estimates and present a summary table comparing the maximum impacts of the LID/GI and fertilizer scenario to those of the WWTF "additional treatment" scenario.

Nitrogen Loadings

For the scenario in which we simulate the application of LID/GI retrofits and a reduction in nitrogen loadings from residential fertilizer, overall impacts on nitrogen loadings are highly dependent on precipitation trends, since both interventions affect loadings that reach the bay via surface water runoff. We therefore present impacts on nitrogen loadings for both the model's default assumptions and for alternate "high precipitation" assumptions where we increase the future average daily precipitation trend, as well as the magnitude and frequency of high-precipitation events. Exhibit 3-20 shows the model's projected average daily precipitation for both the baseline and "high precipitation" assumptions.

EXHIBIT 3-20. PRECIPITATION UNDER BASELINE MODEL ASSUMPTIONS AND ALTERNATIVE "HIGH PRECIPITATION" ASSUMPTIONS

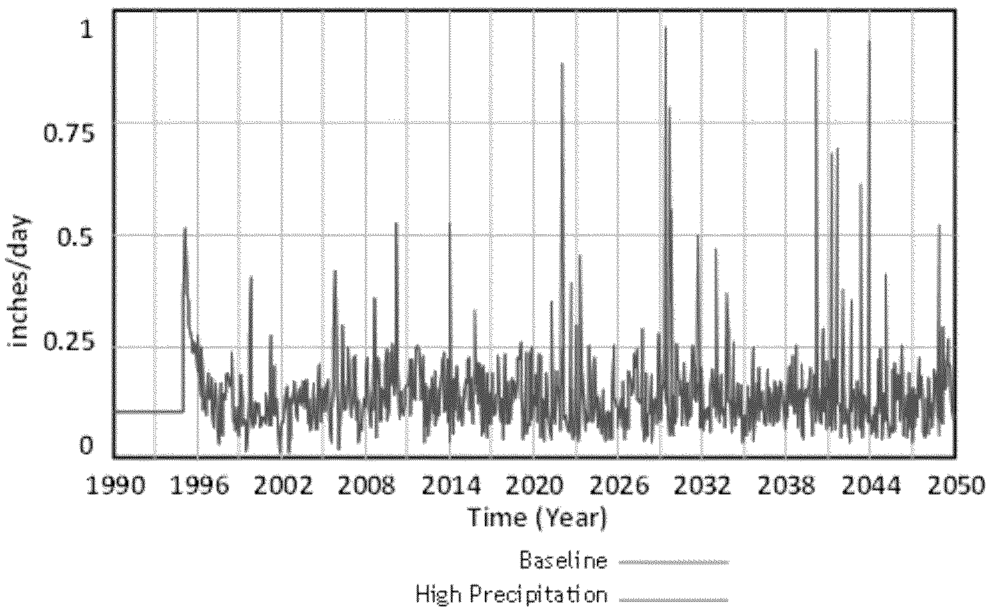


Exhibit 3-21 and 3-22 compare average monthly nitrogen loadings for the LID/GI and fertilizer scenario to the WWTF "additional treatment" scenario. We present this comparison, rather than comparing the LID/GI and fertilizer scenario to the baseline, in order to better illustrate the relative strengths and weaknesses of each intervention. As Exhibit 3-21 shows, on average, treatment upgrades at WWTFs with the largest nitrogen loadings result in lower nitrogen loadings, from 2025 onward (note that the red line is lower than the blue line for most time periods after 2025). On the other hand, the LID/GI and fertilizer scenario targets loadings from surface water runoff, mitigating the harmful impact of extreme precipitation events (note that the blue line is lower than the red line at the "spikes" in 2023, 2024, and 2044). This characteristic of the LID/GI and fertilizer scenario is even more important in light of predicted larger and more frequent extreme precipitation events in the future, as illustrated in Exhibit 3-22. Under the "high precipitation" assumptions, the model estimates that average monthly nitrogen loadings could exceed 1.2 million kg several times in the future, even after upgrading treatment at WWTF facilities. Under the LID/GI and fertilizer scenario, however, the magnitude of these spikes in nitrogen loadings is reduced, potentially reducing the risk of hypoxia, fish kills, or some other adverse environmental impact. As the model suggests, whether WWTF upgrades or LID/GI and fertilizer interventions are preferable for Narragansett Bay depends in part on whether the priority is to reduce average loadings or to reduce the risk posed by extreme events.

EXHIBIT 3-21. AVERAGE MONTHLY NITROGEN LOADINGS IN THE LID/GI AND RESIDENTIAL FERTILIZER SCENARIO AND THE WWTF "ADDITIONAL TREATMENT" SCENARIO (BASELINE PRECIPITATION ASSUMPTIONS)

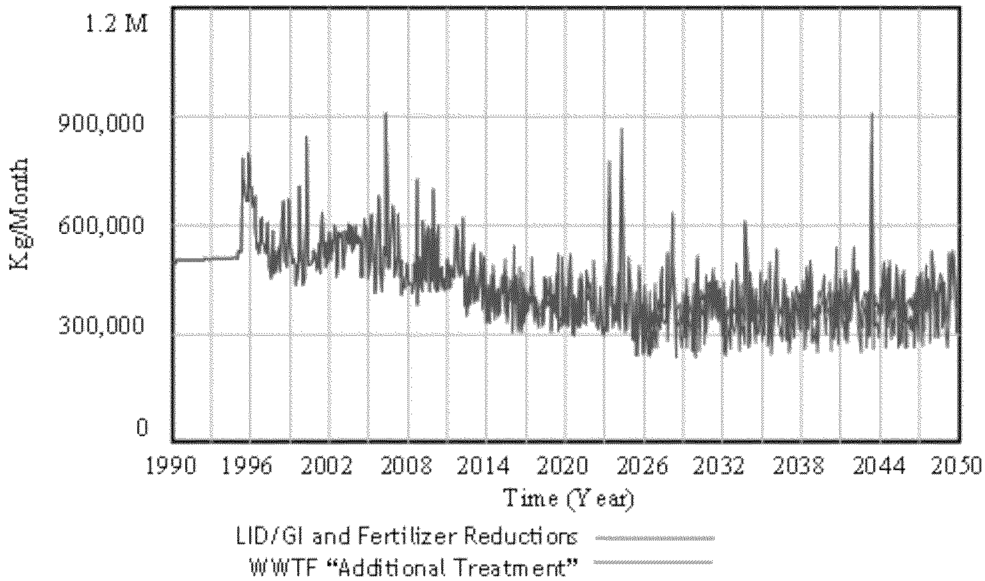


EXHIBIT 3-22. AVERAGE MONTHLY NITROGEN LOADINGS IN THE LID/GI AND RESIDENTIAL FERTILIZER SCENARIO AND THE WWTF "ADDITIONAL TREATMENT" SCENARIO ("HIGH PRECIPITATION" ASSUMPTIONS)

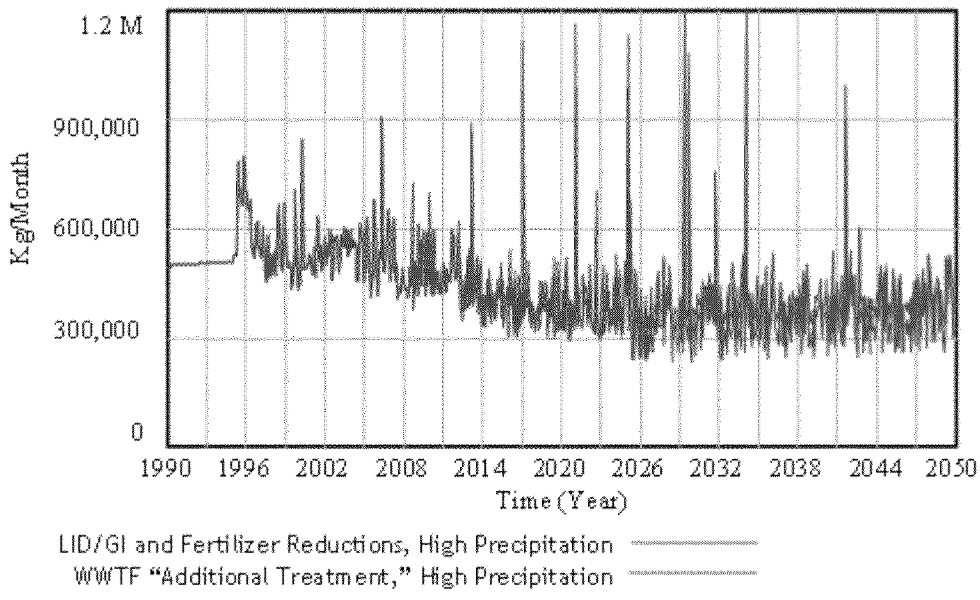
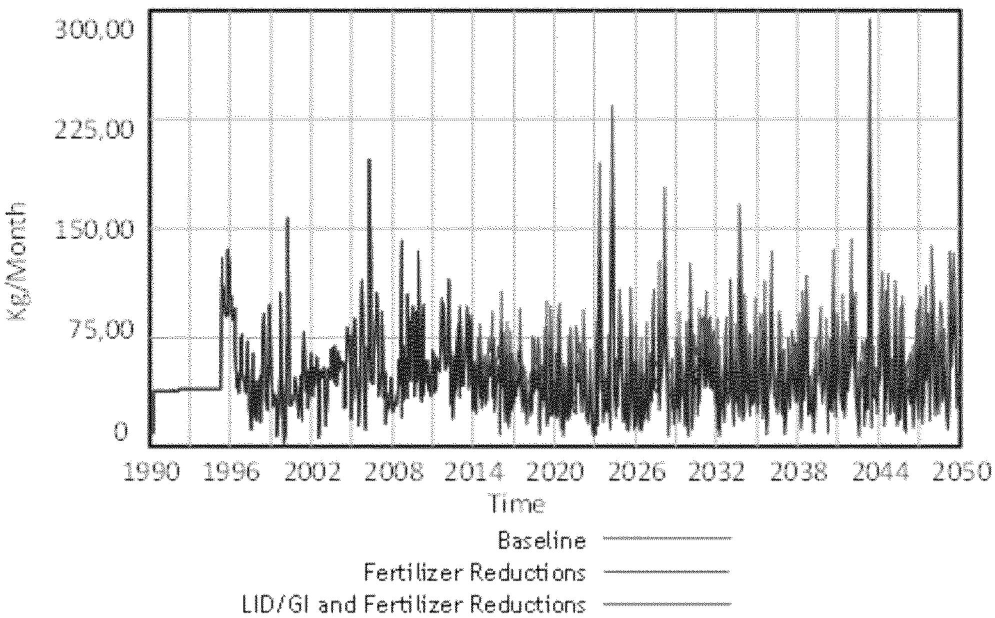


Exhibit 3-23 shows how the LID/GI and residential fertilizer interventions can both affect the same category of loadings, even though the basis for their impacts is fundamentally different. The residential fertilizer intervention aims to reduce the nitrogen content of fertilizer, thereby regulating the source of nitrogen loadings from fertilizer. On the other hand, by reducing the effective imperviousness of the Narragansett Bay watershed, the LID/GI intervention decreases nitrogen loadings through limiting the extent to which nitrogen loadings from fertilizer reach the bay (as well as all other sources that travel to the bay via surface water runoff on developed land). In addition, LID/GI may yield several co-benefits, including those captured in the model (impact of open space on property values) and those that are not (reductions in flood risk and reduced loadings of other pollutants in surface water runoff). As this example illustrates, the Narragansett 3VS model allows users to enter different assumptions about the effectiveness and cost of each intervention and explore whether it might be more or less effective under different circumstances.

EXHIBIT 3-23. AVERAGE SUMMER MONTHLY NITROGEN LOADINGS IN THE BASELINE, RESIDENTIAL FERTILIZER, AND LID/GI AND FERTILIZER SCENARIOS



Costs

Using the cost assumptions described in Section 3-2, the model estimates that the total annualized costs of the LID/GI and fertilizer scenario would be about $32 million per year. Spread over a population of 1.9 million people living in the watershed outside of the lower bay, this results in an annual cost per capita of about $17 per year.

Summary

Exhibit 3-24 compares the results of the LIG/DI and fertilizer scenario to the WWTF "additional treatment" scenario, showing differences from baseline for several indicators in the year 2050. For this comparison, both policy scenarios and the baseline scenario were run with the "high precipitation" assumptions. Overall, the LID/GI and fertilizer scenario reduces average summer monthly nitrogen loadings by about 60 percent of the reduction achieved in the WWTF "additional treatment" scenario. Because this reduction is spread throughout the watershed, rather than concentrated at several WWTFs with large nitrogen loadings, the LID/GI and fertilizer scenario has a smaller impact on nitrogen concentrations in Box 1, a smaller impact on coastal property values due to water clarity, and a smaller impact on summer beach visits. However, because the model estimates a change in property value resulting from increased open space due to LID/GI, the LID/GI and fertilizer scenario has a larger overall impact on property values than the WWTF "additional treatment" scenario, and a larger property tax impact.

EXHIBIT 3-24. SUMMARY OF ENVIRONMENTAL, SOCIAL, AND ECONOMIC INDICATORS FOR THE AQUACULTURE SCENARIO AND THE WWTF "ADDITIONAL TREATMENT" SCENARIO IN 2050

INDICATOR[1]	MODEL OUTPUTS BY SCENARIO (ALL VALUES ARE DIFFERENCES RELATIVE TO BASELINE VALUES)	
	LID/GI AND FERTILIZER	WWTF "ADDITIONAL TREATMENT"
Summer Monthly N Loadings	-53,000 kg/month	-86,000 kg/month
Summer N Concentration at Providence River Estuary North of Fields Point (Box 1)	-0.05 mg/L	-0.28 mg/L
Change in Property Value due to Water Clarity	$53 million	$130 million
Change in Property Value due to Open Space	$260 million	0
Cumulative Property Tax Impact	$94 million	$47 million
Change in Summer Beach Visits	6,300 visits	14,000 visits
Frequency of High Hypoxia Risk (2014-2050)		
Providence River Estuary North of Fields Point (Box 1)	-0.4%	-11%
Greenwich Bay (Boxes 6&7)	-4%	-11%
Frequency of Medium Eel Grass Potential (2014-2050)		
Providence River Estuary North of Fields Point (Box 1)	0.4%	14%
Greenwich Bay (Boxes 6&7)	-1.6%	-1.1%
Annual per Capita Cost (for 30-year financing period)	$17/person/year	$55/person/year
Notes: 1. Unless otherwise indicated, values presented for each indicator are for the entire upper bay region.		

3-4. REFERENCES

Beutel, David. Coastal Resources Management Council. Personal Communication on November 25, 2014.

SECTION 4 | QUALITY ASSURANCE

4-1. INTRODUCTION

This section presents a detailed evaluation of the quality of the model, including assessing the data used to develop the model as well as the relationships that form the model's structure. It includes a description of the steps taken to calibrate the model based on historical data and the output of other models, as well as the results of validation and sensitivity tests designed to assess the model's behavior.

QA OVERVIEW

Models can be classified in many different ways and assessed according to different criteria, such as physical versus symbolic, dynamic versus static, deterministic versus stochastic, etc. In terms of validity, it is important to distinguish between models that are "correlational" (i.e., purely data-driven or "black-box") and models that are "causal-descriptive" (i.e., theory-like or "white-box").

System dynamics models, such as the Narragansett 3VS model, fall into the causal-descriptive category of models. Such models simulate the interactive aspects of real systems and must be validated by assessing both model outputs and the internal structure of the model. By contrast, correlational models, which make no claim of causality in structure, can be validated by comparing the aggregate output behavior of the model to the "real" output within a specified range of accuracy, without assessing the validity of the individual relationships that exist in the model.

Causal-descriptive models are built to assess the effectiveness of alternative policies or design strategies that can improve the behavior of a given system. This is only possible if the model has an internal structure that adequately represents those aspects of the system that are relevant to the problem behavior at hand. A causal-descriptive model, in presenting a "theory" about the real system, must not only reproduce or predict its behavior, but also explain how the behavior is generated, and possibly suggest ways of changing the existing behavior. In short, it is often said that a system dynamics model must generate the "right output behavior for the right reasons."

This section discusses model parameterization (calibration), corroboration (validation, simulation, and sensitivity analysis), and computational reproducibility of the results of the Narragansett 3VS model. The main purpose of these procedures is to ensure that the model is accurate and precise enough to meet the needs of users interested in applying the model to support decision making. The quality assurance information presented in this section has been prepared in accordance with the 3VS quality assurance project plan (QAPP) submitted on September 18, 2013. (Industrial Economics, Inc. 2013).

Overall, the validation tests presented in this section indicate that: (1) the structure produces results consistent with available data, without leading to unrealistic perpetual exponential growth or decay; (2) exogenous parameters are calibrated to be consistent with peer-reviewed studies or historical data; (3) the model reflects real-world phenomena when subjected to extreme-condition tests; and (4) units of measure used in the model are consistent.

4-2. MODEL PARAMETERIZATION (CALIBRATION)

System dynamics models are grounded in causal relationships, and the relationships used in the Narragansett 3VS model are meant to simulate the complexity of interactive environmental, economic, and social aspects of systems. Understanding the data sources and processes used to calibrate the Narragansett 3VS model is therefore central to understanding the strength of the key causal relationships upon which the model is built and how they change over time based on key endogenous drivers of the system.

DATA COLLECTION AND ANALYSIS

To calibrate parameter values in the Narragansett 3VS model, we obtained data and relationships both from historical sources and from other existing simulation models. When relevant historical data were not available, we consulted experts in order to determine baseline assumptions that allow for further calibration and validity testing. These assumptions include parameter values as well as equations that can reproduce observed system behavior.

Historical Data

To set initial values in the model and to calibrate model parameters to reproduce observed data, we obtained historical data for social, economic and environmental variables from a broad range of sources, including published studies, publicly available data, and direct communication with experts. Exhibit 4-1 lists the main variables of the model, the historical data sources consulted to set parameters for each variable, and the geographic area at which each variable is specified. For each variable, the exhibit also notes whether the data sources listed were used as a direct input for a particular parameter or to calibrate the model (i.e., parameters were set so that the model's estimates matched the external data source).

EXHIBIT 4-1. SELECTED VARIABLES, HISTORICAL DATA SOURCES, GEOGRAPHIC AREA, AND USE IN THE MODEL

VARIABLE	DATA SOURCES	GEOGRAPHIC AREA	USE IN THE MODEL
SOCIAL SECTOR			
Total population	NOAA STICS Database	Subwatershed area	Calibration
Total employment	NOAA STICS Database	Subwatershed area	Calibration
Number of households	NOAA STICS Database	Subwatershed area (with RI and MA disaggregation)	Input
ECONOMIC SECTOR			
Disposable income	BEA, US Regional Economic Information System	Rhode Island	Calibration
Real GDP	BEA, US Regional Economic Information System	Rhode Island	Calibration

Agriculture production	BEA, US Regional Economic Information System	Rhode Island	Calibration
Industry production	BEA, US Regional Economic Information System	Rhode Island	Calibration
Services production	BEA, US Regional Economic Information System	Rhode Island	Calibration
Crop and livestock production	BEA, US Regional Economic Information System	Rhode Island	Calibration
Fish landings	RIDEM Standard Atlantic Fisheries Information System (SAFIS) Dealer Reports 2010	Watershed	Input
Tourism consumer surplus per visit	Peconic Estuary recreation survey: Opaluch et al., 1999; Kline and Swallow, 1998	Watershed	Input
Number of beach visits per year	Marisa Mazzotta, personal communication May 2, 2012	Boxes 4, 6, 7, 13	Input
Property value	2011 American Community Survey Census data (U.S. Census Bureau)	Subwatershed area	Input
ENVIRONMENTAL SECTOR			
LAND			
Settlement (developed) Land	Vadeboncoeur, Pryor and Hamburg, 2010	Subwatershed area	Calibration
Agriculture land	Vadeboncoeur, Pryor and Hamburg, 2010	Subwatershed area	Calibration
Forest	Vadeboncoeur, Pryor and Hamburg, 2010	Subwatershed area	Calibration
NITROGEN LOADINGS			
WWTF	<u>Monthly WWTF loadings in MA, 2000-2010</u>: EPA's compliance and enforcement monitoring data. <u>Monthly WWTF loadings in RI, 2000-2010</u>: RIDEM compliance and enforcement monitoring data. <u>Effluent concentrations at selected RI facilities, both current and target limits</u>: Liberti, A. 2010. CHRP/Managers Meeting Presentation. Rhode Island Department of Environmental Management. December 9. <u>Population served, RI facilities</u>: WWTF RIDEM Office of Water Resources listing of Wastewater Facilities and Contacts. <u>Population served, RI facilities</u>: EPA Clean Watersheds Needs Survey 2008 Data and Reports: Detailed listing of Wastewater Treatment Plants Flows and Population Receiving Treatments for State of Massachusetts.	Subwatershed area	Calibration
ISDS	<u>Per capita wastewater N loading coefficients</u>: VHP Model. <u>Sewer system infrastructure, RI</u>: T. Peters, RIDEM, personal communication, March 21, 2012. <u>Sewer system infrastructure, MA</u>: J. Garcia, City of Fall River, personal communication on April 18, 2012; A.M. Teves, City of Taunton, personal communication on April 23, 2012. <u>Locations of buildings or structures, RI</u>: RIGIS, 2012. <u>Soils information</u>: N. Detenbeck, personal communication, August	Subwatershed area	Input

	16, 2012. Average population per building: U.S. Census, 2010. N removal efficiency for baseline and upgraded ISDS: A. Gold, personal communication on May 15, 2012; National Environmental Services Center, 2012; and J. Boyd, personal communication, June 21, 2012.		
Animal waste	Historical livestock populations for the watershed: VHP Model. Total loadings from animal waste, disaggregated by bay box: SPARROW. Precipitation: National Weather Service Forecast Office. Monthly Weather Summary. Providence (TF Green Airport).	Subwatershed area	Calibration
Agricultural fertilizer	Historic fertilizer application rates: VHP Model. Disaggregated agricultural fertilizer loadings: SPARROW. Watershed population: NOAA's Spatial Trends in Coastal Socioeconomics (STICS) projections. Precipitation: National Weather Service Forecast Office. Monthly Weather Summary. Providence (TF Green Airport).	Subwatershed area	Calibration
Residential fertilizer	Fertilizer nitrogen transport coefficients: VHP Model. Total residential fertilizer sales in Rhode Island: Gina Zirkle, Scott's Miracle-Gro Company. Precipitation: National Weather Service Forecast Office. Monthly Weather Summary. Providence (TF Green Airport).	Subwatershed area	Input
Atmospheric Deposition direct to the bay and via the watershed	Historic atmospheric deposition data for 2002 and projected atmospheric deposition data for 2020, disaggregated by bay box: EPA's Community Multi-scale Air Quality model (CMAQ); Dr. Robin Dennis, EPA Atmospheric Modeling and Analysis Division. Trajectory of nitrogen emissions from 2002 to 2020: EPA's Second Section 812 Prospective Analysis of the Benefits and Costs of the 1990 Clean Air Act Amendments. Available at: http://www.epa.gov/air/sect812/prospective2.html. Land use distribution in the watershed and land use category-specific nitrogen transport coefficients: VHP model. Disaggregated nitrogen loadings from atmospheric deposition via the watershed: SPARROW. Distribution of developed land in the watershed: USGS National Land Cover Database (NLCD) 2006 Land Cover. Precipitation: National Weather Service Forecast Office. Monthly Weather Summary. Providence (TF Green Airport).	Whole Bay/ Subwatershed area	Both Input and Calibration
Other Urban	Simple Method formula for estimating total loadings from surface water runoff: Shaver et. Al (2007), North American Lake Management Society in cooperation with U.S. EPA. Original Simple Empirical Method developed by T. Schueler in 1987 and refined by the Center for Watershed Protection in 2003. Nitrogen runoff concentrations: National Stormwater Quality	Subwatershed	

Stormwater	Database (2004), with different values used for open space (0 percent impervious cover) and non-open space (>0 percent impervious cover). Precipitation data: National Weather Service Forecast Office. Monthly Weather Summary. Providence (TF Green Airport). Impervious cover: USGS National Land Cover Database 2001 Percent Developed Imperviousness Version 2.0.		

Other Existing Simulation Models

For some aspects of the model, we relied on other simulation models to fill gaps in historical data or to provide a higher degree of disaggregation for projecting behavior (or outcomes) that otherwise cannot be measured. For example, we used two models to develop the nitrogen loadings module within the Narragansett 3VS model, as indicated in Section 2-6:

- A model of historical nitrogen loadings to Narragansett Bay, developed by Vadeboncoeur, Hamburg, and Prior (hereafter "VHP") (Vadeboncoeur et al., 2010).
- The New England version of the SPARROW (SPAtially Referenced Regressions On Watershed attributes) model, developed by USGS (hereafter "SPARROW") (Milstead, 2012).

The use of these models, which provide different but complementary data related to nitrogen loadings, allowed us to estimate nitrogen loadings dynamically as a function of other variables in the Narragansett 3VS model (e.g., population, impervious surfaces, atmospheric deposition, etc.), while still reproducing observed data. This was possible through the use of: (1) the data inputs employed by these models; (2) the results they generated; and (3) the specific equations used to estimate these results.

Other Existing Studies Providing Selected Model Equations

Certain parameters for model setup and calibration were obtained from existing studies of other water bodies, primarily due to the lack of data specific to Narragansett Bay. These studies generally focus on specific relationships, such as that between nitrogen concentration and Chlorophyll A. Several examples are provided in Exhibit 4-2 below, and a more exhaustive list is provided in Section 2-10.

EXHIBIT 4-2. EXAMPLE RELATIONSHIPS OBTAINED FROM EXISTING STUDIES

OUTPUT	INPUT	SPECIFICATION OF RELATIONSHIP IN MODEL	SOURCES
Chlorophyll A	Nitrogen concentration	Summer: Chlorophyll a (µg / L) = 57.5 * (N concentration in water (g/m^3)) ^2.09 Winter: Chlorophyll a (µg / L) = 10.3 * (N concentration in water (g/m^3) ^1.275	Dettman , E.H., et al. 2005. Load Response Relationships for Nitrogen and Chlorophyll A in Coastal Embayments. In *3rd International Nitrogen Conference: Contributed Papers, Eds.* Zhaoliang Zhu, Katsu Minami and Guangxi Xing. Science Press: Beijing, pp. 531-538.

Ulva growth rate	Nitrogen concentration	We estimate the effect of nitrogen on Ulva growth rate. Percentage growth of ulva per day is equal to: ((Log(N (g N/ m^3)) * 9 + 16.685)/100	Teichberg et al. 2010. Eutrophication and macroalgal blooms in temperate and tropical coastal waters: nutrient enrichment experiments with Ulva spp. Global Change Biology. Vol 16, pp. 2624-2637.
Property Value	Water Clarity (Secchi depth)	We model changes in property value in residential structures adjacent to the bay based on the estimate that a one meter increase in Secchi depth leads to a three percent increase in property value.	Boyle, KJ, et al. 1998. Lakefront Property Owners' Economic Demand for Water Clarity in Maine Lakes. Miscellaneous Report 410. University of Maine: Maine Agricultural and Forest Experiment Station. Gibbs, J, et al. 2002. An Hedonic Analysis of the Effects of Lake Water Clarity on New Hampshire Lakefront Properties. Agricultural and Resources Economics Review 31(1): 39-46. Walsh, P, Milon, W., and Scrogin, D. 2010. The Spatial Extent of Water Quality Benefits in Urban Housing Markets. Working Paper Series. U.S. Environmental Protection Agency: National Center for Environmental Economics, Washington, DC: 35. Baseline Property values derived from 2007-2011 American Community Survey Data, U.S. Census.
Fishing (Commercial Finfish)	Annual nitrogen loadings per kilometer of basin surface water	We model commercial finfish using an empirical relationship between finfish abundance and nitrogen loadings from Brietburg et al. 2009. We calculate the relative change in the commercial landings and apply this to estimates of commercial finfish caught in Narragansett Bay: f=2.83+0.99 × exp{ 〖-0.5 [(x- 4.08)/0.45]〗 ^2 } where x is the log N loadings in log10kg km-2 yr-1. The modeled relationship is inverted "U" shaped and there is debate on which side of the "U" the bay is on. The model predicts that at current levels of nitrogen loading, increased loading will decrease commercial fin fish landings. We scale total commercial fish landings to exclude commercial fish caught in the lower bay	Breitburg, D.L. et al. 2009. Hypoxia, Nitrogen, and Fisheries: Integrating Effects Across Local and Global Landscapes. Annual Review of Marine Science 1: 329-349. Tyrrell, Timothy J., Maureen F. Devitt, and Lynn A. Smith. The Economic Importance of Narragansett Bay. Final Report Prepared for: The Rhode Island Department of Environmental Management - Narragansett Bay Project and The Rhode Island Sea Grant College Program. November 4, 1994. RIDEM Standard Atlantic Fisheries Information System (SAFIS) Dealer Reports. Personal communication with John Scotti on October 4, 2011. Personal communication with Phil Colarusso on May 15, 2012.

Water Clarity (Secchi depth)	Chlorophyll A	Secchi depth (meters) = 2.83 - 0.09*(Chl A (µg / L)) + 0.000776 * (Chl A (µg / L))^2, if 0 < Chl A (µg / L) <= 39; otherwise Secchi depth (meters) = 0.5.	Regression analysis of Narragansett Bay data from the NOAA National Coastal Assessment Northeast Database: Years 2000 to 2006. Data and Stata ".do" files available upon request.

Given that the Narragansett 3VS model uses causal relationships to generate projections for all the variables included in the model, it is important to ensure that the information obtained from various data sources represents a coherent system that produces consistent results. To accomplish this goal, we tested historical data, model results and equations and parameters obtained from existing studies within an integrated framework.

For example, consistency checks were carried out when using nitrogen loadings to estimate nitrogen concentrations. In this case we combined information on four different elements, including (a) historical and modeled data on loadings (derived from the SPARROW and VHP models), (b) model results on residence time (Abdelrhman, 2004), (c) denitrification (Dettman, pers. comm.), and (d) model equations for nitrogen flow across boxes (EcoGEM model (Kremer, J. et al. 2010), Mark Brush and Jamie Vaudrey (pers. comm.)) to generate results consistent with observed data on nitrogen concentration by box (Krumholz and Oviatt, 2012).

SYSTEMIC MODEL CREATION

Once we estimated model parameters, using the data sources listed above, we developed the model by first creating and then linking separate modules (e.g., for population, nitrogen loadings from wastewater and surface water runoff, nitrogen concentrations, beach visits, and property value). In this phase, outputs from some modules were used as inputs into other modules, creating a cross-sectoral causal network. This process is systematic, as there are precise steps to follow and validation tests to perform, as well as systemic, given that various modules have to be linked horizontally (i.e., across sectors). This process allows us to identify any incorrect sectoral parameters, as errors in one sector would be propagated to others, and to carry out a more precise and comprehensive calibration. Exhibit 4-3 (which is a simplified version of Exhibit 2-1) illustrates the cross-sectoral linkages included in the model.

Model Input Characterization and Assessment

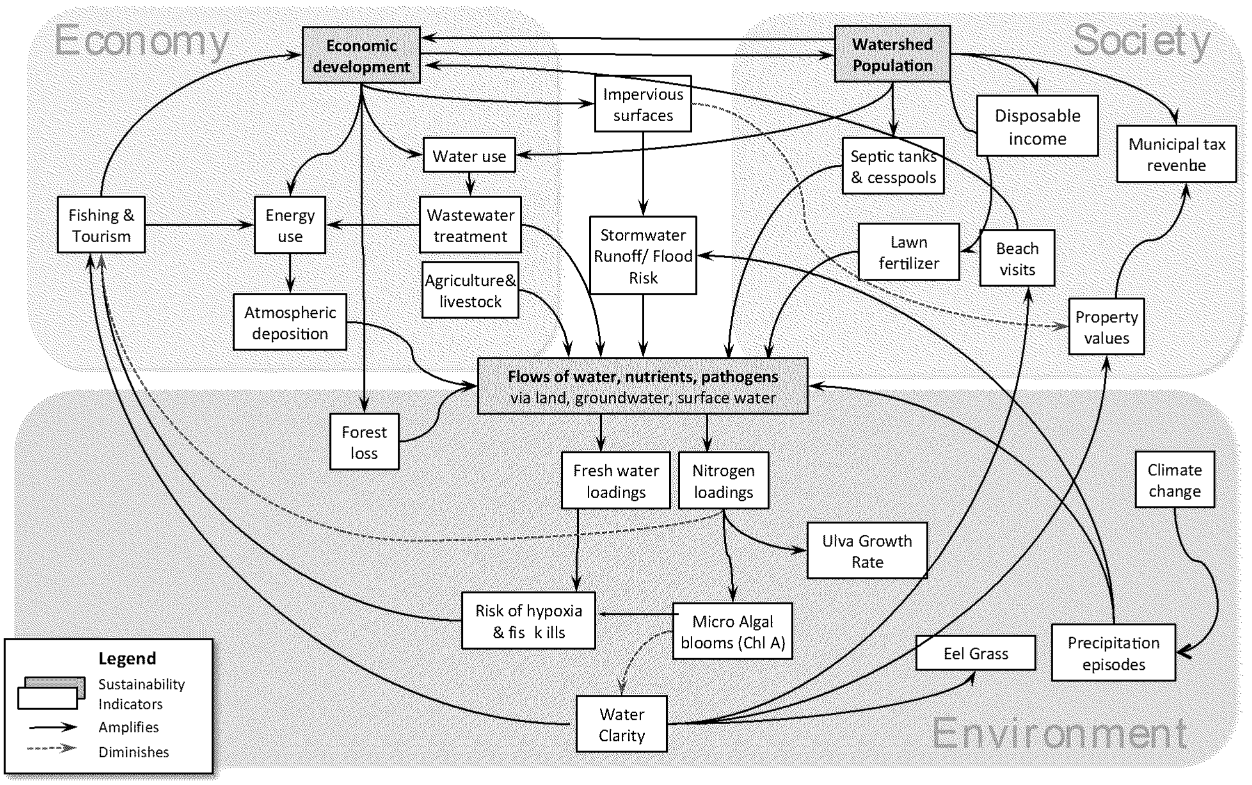
As part of the quality assurance process in developing the Narragansett 3VS model, we assessed the quality of model inputs, both data sources and any methods used to manipulate them for use in the model. The results of this assessment are a qualitative ranking of the level of confidence in the model input (high, medium or low) and a description of the associated uncertainties. The process for determining the level of confidence in an input is based on applying a weight of evidence approach to the following criteria:

- Is the input based on information from one or more externally peer reviewed documents?
- Is there agreement in the literature or within the relevant community of practitioners about the underlying data or method for the input? Or are there conflicting viewpoints?
- Do the characteristics of the input make it suitable for use in the context of Narragansett Bay? For example, is the input based on data from either Narragansett Bay or another area with similar characteristics; or is it based on data from another area that is highly site-specific?

- If the model input is based on manipulation of a data set, is the method used in developing the input an established and widely applied approach? If the method applies equations developed from external models, are those equations applied to local data in an appropriate manner?

The assessment results are presented in Exhibit 4-4. For each input, we provide the source, how the input is used in the model, the rationale for selecting the input, and the confidence level in the input, along with a description of uncertainties associated with it.

EXHIBIT 4-3. SCHEMATIC OF ECONOMIC, SOCIAL, AND ENVIRONMENTAL VARIABLES AND RELATIONSHIPS IN THE NARRAGANSETT 3VS MODEL



Model Output Uncertainty Characterization

As an extension of the assessment and characterization of model inputs, we also characterized the varying degrees of confidence in the model's outputs. For each social, economic, and environmental indicator estimated by the model, we determined how many of the model inputs causally linked to the indicator are classified as having high, medium, or low confidence levels. These assessment results, listed in Exhibit 4-5, provide a qualitative scale of confidence for model outputs that is meant to complement the quantitative validation and sensitivity analyses presented later in this section and in Section 4-3. In addition, this uncertainty characterization can be used by model users to target specific model inputs for scenario-specific sensitivity analyses in order to determine the extent to which uncertainty in their values can affect scenario results. Note that some inputs appear for multiple categories (e.g., population and precipitation), so the numbers reported for high, medium, and low confidence levels for larger categories (e.g., total nitrogen loadings) do not always equal the sum of all numbers reported for sub-categories (e.g., nitrogen loadings from residential fertilizer).

EXHIBIT 4-4. MODEL INPUT CHARACTERIZATION AND ASSESSMENT

MODEL INPUT	SOURCE	HOW INPUT WILL BE USED	RATIONALE FOR SELECTING SOURCE	CONFIDENCE LEVEL AND NOTES ON UNCERTAINTIES ASSOCIATED WITH INPUT
Drivers affecting Nitrogen loadings to Narragansett Bay over time.	(1) Vadeboncoeur, Matthew A., Steven P. Hamburg, and Donald Pryor. "Modeled Nitrogen Loading to Narragansett Bay: 1850 to 2015." Estuaries and Coasts 33.5 (2010): 1113-127. (2) Additional data provided by Matthew Vadeboncoeur at Center for Environmental Studies, Brown University; and by Donald Pryor at Complex Systems Research Center, University of New Hampshire.	Used to relate nitrogen loadings from specific source categories (e.g., ISDS, animal wastes, agricultural fertilizer, atmospheric deposition on the watershed) to other variables in the model (e.g., population not connected to sewers, animal stock, cultivated land, land cover patterns).	This was the most recent and comprehensive study that related nitrogen loadings from different source categories to other variables that could be estimated endogenously in the model.	HIGH: Vadeboncouer, Hamburg, and Pryor (VHP) performed longitudinal validation on their model, finding that modeled loadings corresponded fairly closely to historical loadings data in Narragansett Bay. This validation lends credence to our use of their model's equations to relate nitrogen loadings to other variables.
2002 Nitrogen loadings from animal waste, agricultural fertilizer, and atmospheric deposition on the watershed, disaggregated by Bay Box.	(1) USGS New England SPARROW Model; Moore, Richard B., Craig M. Johnston, Richard A. Smith, and Bryan Milstead. "Source and Delivery of Nutrients to Receiving Waters in the Northeastern and Mid-Atlantic Regions of the United States." Journal of the American Water Resources Association. 47.5 (2011): 965-90 (2) SPARROW outputs for Narragansett Bay provided by Milstead, B. 2012. Personal Correspondence, including "SparrowDSS_InputsToNarBay" Spreadsheet and GIS Data. June 4	Used to calibrate total loadings from specified categories and disaggregate them by regions of the bay.	SPARROW allows for geographic disaggregation of loadings by bay box. We used SPARROW to estimate nitrogen loadings to Narragansett Bay, except in cases where better data were available (wastewater treatment facilities) or where we expected substantial nitrogen loadings to occur outside of rivers (ISDS, suburban fertilizer, atmospheric deposition direct to the bay).	HIGH: SPARROW is a national model that is calibrated to maximize the fit between predicted and measured nitrogen loadings in local rivers. There is some uncertainty over whether SPARROW's estimates of total nitrogen loadings include ISDS, which is expected to travel via groundwater.

Method for estimating Nitrogen loadings from surface water runoff	(1) Simple Empirical Method Model from Shaver, E., Richard Horner, Joseph Skupien, Chris May, and Graeme Ridley. (2007). Fundamentals of Urban Runoff Management. 2nd Edition. North American Lakes Management Society. (2) National Land Cover Database 2001 Percent Developed Imperviousness Version 2.0. (3) Nitrogen runoff concentrations obtained from the National Stormwater Quality Database (2004).	The Simple Empirical Method estimates total surface water runoff as a function of (1) impervious surface area, (2) stormwater runoff pollutant concentrations, and (3) annual precipitation. We used nitrogen runoff concentration data from the National Stormwater Quality Database, local precipitation data, and local impervious surface area data from the USGS dataset. We estimated runoff loadings for developed land and open space separately.	The Simple Empirical Method allows the model to demonstrate how loadings from surface water runoff might change if impervious cover increases (due to standard development) or decreases (due to low-impact development). It also relates surface water runoff loadings to precipitation.	MEDIUM: Due to data limitations, we used the same nitrogen runoff concentrations for all developed land in the watershed, rather than estimating runoff separately for different land use types. Additional data quality concerns are associated with the impervious cover dataset (see below)
Nitrogen loadings from Wastewater Treatment Facilities (WWTFs)	(1) Effluent concentrations and flows from: Weitzler, Ellen. U.S. EPA Region 1. 2012. “WWTF_NLoad_Summary from EPA” Spreadsheet, based on effluent concentration and flow data from RIDEM and EPA Compliance and Enforcement Monitoring data. (2) Population served from: WWTF RIDEM Office of Water Resources listing of Wastewater Facilities and Contacts; EPA Clean Watersheds Needs Survey 2008 Data and Reports: Detailed listing of Wastewater Treatment Plants Flows and Population Receiving Treatments for State of Massachusetts. (3) Target limits for 2014 from: Liberti, A. 2010. CHRP/Managers Meeting Presentation. RIDEM. December 9	Monthly average effluent nitrogen concentrations and flow data were used to estimate total monthly nitrogen loadings for each WWTF for the years 2000-2010. We then divided total loadings by the population served by each facility to derive per-capita loadings values for each region of the watershed. For agreed-upon reductions in nitrogen loadings through 2014, we used RIDEM data on targeted effluent limits to estimate revised per-capita loadings values.	Compliance and Enforcement Monitoring data provided monthly estimates of loadings at the point of discharge from WWTFs. Dividing total loadings for each facility by population served allowed us to estimate WWTF loadings as a function of sewered population in the watershed.	HIGH: All WWTFs in the Narragansett Bay watershed discharge either directly into the bay or into large rivers, and documentation from SPARROW suggests that attenuation of nitrogen only takes place in smaller streams. Compliance and Enforcement Monitoring data allowed us to capture seasonal variation at the facility level, based on observed data.
Population	(1) NOAA Spatial Trends in Coastal Socioeconomics Database; (2) U.S. Census Bureau (3) Woods and Poole Economics, Inc.	Population is used as a driver of nitrogen loadings from WWTF and ISDS. Population also affects land use as well as nitrogen loadings from agricultural and residential fertilizer. Population is also used to estimate the per capita cost of policy interventions.	Provides information on population disaggregated by subwatershed area, both for historical data and future trends.	HIGH: Historical data are from the U.S. Census Bureau, regularly collected and validated. Projections are consistently generated by Woods and Poole Economics, Inc. with a methodology tested and validated for all U.S. county and metropolitan areas.

Precipitation	(1) NOAA National Weather Service Forecast Office. Monthly Weather Summary; Weather station in Providence (TF Green Airport).	Precipitation is a key driver of several nitrogen loading categories (e.g. atmospheric deposition and runoff).	Provides measured and validated monthly information on precipitation, allowing for seasonal analysis.	HIGH: Historical Data Historical data are provided by the National Weather Service Forecast Office. MEDIUM: Future Projections We analyze historical data to forecast future rainfall variability.
Imperviousness	(1) National Land Cover Database 2001 Percent Developed Imperviousness Version 2.0. (2) U.S. Environmental Protection Agency. 2011. Integrated Climate and Land Use Scenarios (ICLUS) GIS Tools.	Percent imperviousness is used to estimate total nitrogen loadings from surface water runoff. Implementing low-impact development (LID) or green infrastructure (GI) is modeled by changing the percent impervious cover in a particular region within the Narragansett Bay watershed. The LID/GI use case shows the impacts of open space on property values; it uses the ICLUS dataset because it projects both impervious cover and housing density.	The USGS impervious cover dataset provided the finest resolution data on imperviousness that covered both Rhode Island and Massachusetts portions of the watershed. The ICLUS dataset provided a means of projecting changes in impervious cover for the baseline scenario in a way that was consistent with projected changes in housing density.	MEDIUM: USGS and ICLUS impervious cover data may not account for existing reductions to effective imperviousness (e.g., pervious pavement in parking lots.)
Atmospheric Deposition	(1) USEPA. 2012. EPA Community Multi-scale Air Quality (CMAQ). Available at: http://www.epa.gov/AMD/CMAQ/ CMAQ outputs for 2020 based on projected emissions from the following: (2) USEPA. 2011. EPA's Second Section 812 Prospective Analysis of the Benefits and Costs of the 1990 Clean Air Act Amendments. Available at: http://www.epa.gov/air/sect812/prospective2.html.	We used GIS data with CMAQ-generated deposition estimates for 2002 and 2020 to estimate direct deposition to Narragansett Bay and deposition onto the watershed.	CMAQ provided spatial data with deposition estimates based both on historical data (2002) and projections of air emissions in the future (2020). CMAQ is "a state-of-the-science, regional air quality modeling system that is designed to simulate the physical and chemical processes that govern the formation, transport, and deposition of gaseous and particulate species in the atmosphere" (USEPA, 2011)	HIGH: Deposition estimates for 2002 are based on data from EPA's National Emissions Inventory. The CMAQ outputs used in EPA's Second Section 812 Prospective Analysis were evaluated using the Atmospheric Model Evaluation Tool (AMET). MEDIUM: Future projections of deposition are based on economic modeling from a national study. Assumptions used in that modeling effort may not be accurate for the Narragansett Bay region.

Nitrogen loadings from Independent Sewage Treatment Systems (ISDSs)	(1) A. Gold, University of Rhode Island, personal communication on May 15, 2012; (2) J. Boyd, Coastal Resources Management Council, personal communication, June 21, 2012.	To determine the amount of nitrogen loadings from ISDSs in the watershed. These data are combined with data from the Vadeboncoeur (VHP) model, described above. We used GIS software to map the sewer system infrastructure in the watershed and estimate the number of people using ISDSs that discharge into the bay. These systems were identified based on whether they are located outside areas with sewer system connectivity and on soils with high infiltration rates near rivers and streams leading to the bay. To determine the amount of nitrogen that these systems contribute to the bay, we relied on information provided by local experts.	The VHP model estimates nitrogen loadings for wastewater from the non-sewered population, but SPARROW does not. However, based on discussions with stakeholders and EPA, it was decided that the VHP model likely overestimates loadings from ISDSs. We selected the identified sources because they are recognized as experts in the field of watershed hydrology.	MEDIUM: This estimate is specific to Narragansett Bay and based on detailed GIS modeling using the most recent available data. One uncertainty associated with this input is how much nitrogen is removed by typical ISDSs. In addition, SPARROW does not estimate ISDS loadings separately, so we estimated ISDS loadings in addition to the totals that SPARROW estimates for other categories. There is uncertainty regarding whether SPARROW's estimates of total loadings (which are calibrated to equal total flux from rivers) include the loadings which we estimate in this category.
Nitrogen loadings from Residential Fertilizer	(1) Zirkle, Gina. 2012. Scott's Miracle-Gro Company, personal communication. (2) Vadeboncoeur, Matthew A., Steven P. Hamburg, and Donald Pryor. "Modeled Nitrogen Loading to Narragansett Bay: 1850 to 2015." Estuaries and Coasts 33.5 (2010): 1113-127.	We used data on the nitrogen content of Rhode Island residential fertilizer sales to estimate pre-capita nitrogen application rates for residential fertilizer for Rhode Island, which we applied to the population of the Narragansett Bay watershed. We estimated the amount of nitrogen that reaches the bay from lawns using parameters from the VHP model.	Scott's Miracle-Gro company accounts for approximately 50 percent of the residential fertilizer market in Rhode Island.	MEDIUM: We were not able to validate these estimates with observed data (SPARROW does not estimate loadings from residential fertilizer as a separate category). The Miracle-Gro Company recommended using nitrogen runoff parameters for lawns that were lower than the parameters from the VHP model.

Nitrogen Loadings from Other Urban Stormwater	Model Calculations	We assume that nitrogen loadings from surface water runoff include residential fertilizer, agricultural fertilizer, animal waste, atmospheric deposition on the watershed in developed and undeveloped land, and other urban sources. We estimate nitrogen loadings for other urban stormwater by estimating total nitrogen loadings and subtracting the loadings estimates from the other five categories.	Stakeholder feedback suggested that the five subcategories of surface water runoff that we estimate directly (residential and agricultural fertilizer, animal waste, and atmospheric deposition on developed and undeveloped land in the watershed) do not account for all loadings from surface water runoff, so we created a sixth subcategory for other urban stormwater. We did not identify a means of estimating nitrogen loadings from other urban stormwater directly, so we calculated it as a residual.	LOW: Because we estimate other urban stormwater loadings as a residual (i.e., the result after subtracting several other categories of loadings from an estimate of total loadings from runoff), this estimate is affected by uncertainty in the other loadings estimates.
Spatial Distribution of Nitrogen Loadings	(1) Vadeboncoeur, Matthew A., Steven P. Hamburg, and Donald Pryor. "Modeled Nitrogen Loading to Narragansett Bay: 1850 to 2015." Estuaries and Coasts 33.5 (2010): 1113-127. (2) USGS New England SPARROW Model; Moore, Richard B., Craig M. Johnston, Richard A. Smith, and Bryan Milstead. "Source and Delivery of Nutrients to Receiving Waters in the Northeastern and Mid-Atlantic Regions of the United States." Journal of the American Water Resources Association. 47.5 (2011): 965-90 (3) Model Calculations	The VHP model disaggregated the Narragansett Bay watershed into eight areas defined by municipal boundaries that roughly correspond to subwatershed boundaries, while the SPARROW model provided spatially disaggregated loadings estimates for each of the rivers flowing into Narragansett Bay, allowing us to estimate loadings for different regions, or "boxes" of the bay. For each loadings category, we applied different methods to translate disaggregated loadings estimates by subwatershed area into disaggregated loadings estimates by bay box (see Exhibit 2-11).	For policy purposes, it is important for the model to be able to show how different parts of the watershed contribute to total nitrogen loadings to Narragansett Bay. Because the bay is not homogeneous, the model also needed to be able to show how the environmental impacts of nitrogen pollution vary for different regions of the bay. The VHP model and the SPARROW model allowed us to incorporate both levels of spatial disaggregation into the model.	MEDIUM: The degree of confidence that we have in the spatial disaggregation of loadings estimates varies by category, with some categories (e.g., WWTF loadings and agricultural fertilizer) having higher confidence than other categories (e.g., residential fertilizer and other urban stormwater).

Seasonal Distribution of Nitrogen Loadings	(1) WWTF data from: Weitzler, Ellen. USEPA. 2012. "WWTF_NLoad_Summary from EPA" Spreadsheet, based on effluent concentration and flow data from RIDEM and EPA Compliance and Enforcement Monitoring data. (2) Fertilizer data from: model assumption.	For WWTF loadings, monthly effluent concentration and flow data were used to estimate monthly nitrogen loads by facility. For residential and agricultural fertilizer, we assumed that 80 percent of loadings occurred between April and September, while the remaining 20 percent occurred between October and March. Loadings from other categories were assumed to be distributed evenly across all months.	With the exception of WWTF loadings, our data allowed us to estimate only annual loadings. We then applied reasonable assumptions to distribute a portion of annual loadings to the summer (April-September) or the winter (October-March). Within each season, loadings are distributed evenly across each month.	MEDIUM: While we have high confidence in the temporal distribution of loadings from WWTFs, we have less confidence in the assumptions used to distribute annual loadings from other sources.
Nitrogen Circulation in the Bay	(1) Vaudrey, J. PhD. University of Connecticut. Faculty of Marine Sciences. Personal communication: 2012. (2) Brush, M. Associate Professor of Marine Science. Virginia Institute of Marine Science. Personal communication. 2012. (3) Dr. Jason Krumholz, University of Rhode Island Graduate School of Oceanography. Personal communication: 2012. (4) Abdelrhman, M. 2004. Simplified modeling of flushing and residence times in 42 embayments in New England, USA, with special attention to Greenwich Bay, Rhode Island. Estuarine Coastal and Shelf Science, 62, 339-351. (5) Kremer, J. et al. 2010. Simulating property exchange in estuarine ecosystem models at ecologically appropriate scales. Ecological Modeling. 221: 108-1088.	The nitrogen circulation process allows for differentiated levels of nitrogen concentration across Narragansett Bay. This allows for variation in environmental and economic indicators across the bay.	Combining the sources selected allows for the construction of a modified box model using residence times. This approach allows for model results to mimic the variability of nitrogen concentration across different areas of the bay that is caused by biophysical processes.	MEDIUM: The nitrogen circulation method is based on peer reviewed sources. However, nitrogen circulation is a complex process. The simplified representation used in the 3VS model has not been peer reviewed and by necessity lacks the biophysical realism required to fully reflect the complexity of the actual circulation patterns in the bay.
Nitrogen Losses in the Bay (30 percent per year)	(1) Ed Dettmann. Research Environmental Scientist, U.S. EPA Office of Research and Development, Atlantic Ecology Division. Pers. Comm. 2012.	The factor for nitrogen losses in the bay is intended to reflect nitrogen loss through sedimentation, denitrification, and other nitrogen processes. Including this relationship increases the biophysical realism of the 3VS model.	Dr. Dettmann research focuses on effects of nitrogen in Narragansett Bay.	MEDIUM: Dr. Dettmann's estimate is specific to Narragansett Bay, but is not a published figure from the peer-reviewed literature.

Effect of Nitrogen Loading on Chlorophyll	(1) Dettmann, E.H., et al. 2005. Load Response Relationships for Nitrogen and Chlorophyll A in Coastal Embayments. In 3rd International Nitrogen Conference: Contributed Papers, Eds. Zhaoliang Zhu, Katsu Minami and Guangxi Xing. Science Press: Beijing, pp 531-538.	This relationship links nitrogen concentration to Chlorophyll A concentrations, which is used as an input in other relationships, e.g. Secchi depth, eel grass potential, and hypoxia risk.	This peer-reviewed paper provides a Narragansett Bay specific relationship.	HIGH: This estimate is specific to Narragansett Bay and published in the peer-reviewed literature.
Effect of Nitrogen Loading on Relative Sea Lettuce (ULVA) Growth Rate	(1) Teichberg et al. 2010. Eutrophication and macroalgal blooms in temperate and tropical coastal waters: nutrient enrichment experiments with Ulva spp. Global Change Biology. Vol 16, pp. 2624-2637.	This relationship links nitrogen concentration to sea lettuce growth. Sea lettuce growth is an environmental endpoint in the 3VS model.	Teichberg et al. (2010) is a published source that relates ulva growth rate to nitrogen concentration.	MEDIUM: The selected relationship is peer-reviewed, but is not specific to Narragansett Bay. It represents the growth rate of Ulva during peak growing season, which is a likely over estimate for other periods represented in the model. The relationship is an endpoint in the model, limiting the scope of the impacts of this potential overestimation.
Effect of Micro Algae (Chlorophyll A) on Secchi Depth	(1) Regression analysis of Narragansett Bay data from the NOAA National Coastal Assessment Northeast Database: Years 2000 to 2006. (2) Dr. Jason Krumholz, University of Rhode Island Graduate School of Oceanography. Personal communication: 2012.	The relationship estimates the effect on Secchi Depth of Chlorophyll A. Secchi depth is a measure of water clarity, which is used in subsequent relationships, such as beach visits and property values.	Analyzing local data is believed to provide a more accurate estimate of the Narragansett Bay relationship than transferring relationships in the published literature from other water bodies.	MEDIUM: The regression analysis of local data follows standard regression practices, but the result has not been published in the peer-reviewed literature.
Eelgrass Improvement Potential	(1) Short, F., Burdick, D., and J. Kaldy. 1995. Mesocosm experiments quantify the effects of eutrophication on eelgrass, Zostera marina. Limnol. Oceanog. 40(4), 740-749; 2003 Rhode Island Eelgrass Transplant Suitability Metadata. Available at: http://www.narrbay.org/d_downloads/D_Biological/D_habitat/eelgrtrans.htm (2) Dr. Jason Krumholz, University of Rhode Island Graduate School of Oceanography. Personal communication: 2012.	The eelgrass improvement potential metric provides a qualitative indication of the potential for eelgrass improvement with changes in clarity and area of eelgrass transplant suitability. It is used as an endpoint in the model.	Water clarity is a known influence on eelgrass growth. The Eelgrass Transplant Suitability data synthesizes data on bathymetry, temperature, light, current eelgrass, and historic eel grass. Combining these factors indicates the potential for eelgrass improvement from water clarity improvements.	LOW: This is a qualitative index, which provides the user with an indication of the relative benefit to eelgrass of water clarity improvements for areas across the bay.

Hypoxia Risk	(1) Bricker, S. Ferriera, J. and T. Simas. 2003. An Integrated methodology for assessment of estuarine trophic status. Ecological Modeling. Vol 169: pp. 39-60. (2) Dr. Jason Krumholz, University of Rhode Island Graduate School of Oceanography. Personal communication: 2012.	The hypoxia risk metric provides a qualitative indication of the hypoxia risk from summer precipitation, summer chlorophyll A concentration, and location in the bay. It is used as an endpoint in the model.	The three risk factors of precipitation, chlorophyll A, and location are generally agreed upon as important contributors in hypoxic events. A quantitative relationship is beyond the scope of the 3VS model.	LOW: This is a qualitative index built on peer reviewed literature. It provides the user with an indication of the relative hypoxia risk in the bay from key risk factors. Hypoxia is a complex event that is not fully captured in this relationship.
Effect of Nitrogen on Fin Fish Landings	(1) Breitburg, D.L. et al. 2009. Hypoxia, Nitrogen, and Fisheries: Integrating Effects Across Local and Global Landscapes. Annual Review of Marine Science 1: 329-349 (2) Scotti, J., Senior Fisheries Specialist at Cornell University, personal communication on April 23, 2012 (3) Atlantic Coastal Cooperative Statistics Program. 2010. Standard Atlantic Fisheries Information System (SAFIS) (4) Tyrell, T., M. Devitt, and L. Smith. 1994. The Economic Importance of Narragansett Bay. Kingston, RI: University of Rhode Island; (5) Colarusso, P., Ocean and Coastal Protection Unit U.S. EPA Region I, personal communication on May 15, 2012.	This relationship provides a connection between nitrogen loading and finfish landings. This relationship is used to scale changes in finfish landings from historical values. Values for finfish landings are considered in GDP.	The source provides a quantitative relationship between nitrogen loadings and finfish landings by examining estuaries and embayments across the globe. The Narragansett specific landings data allows the model to tailor the Breitburg relationship to the appropriate scale for Narragansett Bay.	LOW: The effect of nitrogen on finfish is an area of active debate and research in Narragansett Bay. Researchers disagree of the direction of the effect on finfish population from Nitrogen reductions. Some researchers assert that further reductions in Nitrogen could reduce finfish populations and other researchers assert that further reductions would be beneficial to finfish populations.
Effect of Water Clarity on Beach Visits	(1) Marisa Mazzotta, Atlantic Ecology Division, personal communication May 2, 2012; (2) Diamantides, J. 2000. Relating objective and subjective measures of water quality in the travel cost method: An application to the Peconic Estuary System. University of Rhode Island; (3) Opaluch, J.J., Grigalunas, T., Diamantides, J., Mazzotta, M., and Johnston, R. 1999. Recreational and Resources Economic Values for the Peconic Estuary System. Final Report Prepared for the Peconic Estuary Program; (4) Kline, J.D., and Swallow, S.K. 2008. The demand for local access to coastal recreation in southern New England. Coastal Management, 26:3, 177-190.	We model changes in beach visitation associated with changes in water clarity (Secchi depth) for seven beaches located within the study area. Based on the results of a doctoral dissertation on the Peconic Bay (Diamantides 2000), we estimate that a one percent change in water clarity translates into a 0.56 percent change in the number of beach visits.	Data was unavailable to directly relate changes in nitrogen concentration to changes in beach visitation. We therefore used the relationship established by Diamantides to relate beach visits to water clarity, which in turn is related to nitrogen through other relationships in the mode. See 'Effect on Micro Algae on Secchi Depth' and 'Effect on Nitrogen Loading on Chlorophyll.'	MEDIUM: This relationship is not specific to Narragansett Bay, but Dr. Diamantides is an expert in the field of environmental and natural resource economics.

Effect of Water Clarity on Property Value	(1) Gibbs, J, et al. 2002. An Hedonic Analysis of the Effects of Lake Water Clarity on New Hampshire Lakefront Properties. Agricultural and Resources Economics Review 31(1): 39-46; (2) Walsh, P, Milon, W., and Scrogin, D. 2010. The Spatial Extent of Water Quality Benefits in Urban Housing Markets. Working Paper Series. U.S. Environmental Protection Agency: National Center for Environmental Economics, Washington, DC: 35; (3) Boyle, KJ, et al. 1998. Lakefront Property Owners' Economic Demand for Water Clarity in Maine Lakes. Miscellaneous Report 410. University of Maine: Maine Agricultural and Forest Experiment Station. (4) United States Census Bureau. 2011. American Community Survey 2011 5-year estimates for Massachusetts and Rhode Island, available at American FactFinder, http://factfinder.census.gov/home.	We estimate a relationship between changes in water clarity and property value based on three studies that provide estimates of the percent change in property value for waterfront properties resulting from changes in Secchi depth (Gibbs et al., 2002; Walsh, Milon and Scrogin, 2010; and Boyle et al., 1998). Based on these studies, we estimate that a one meter increase in Secchi depth results in a three percent increase in property value. For the model, we estimate waterfront residential property values for the bay using census block groups from the 2011 American Community Survey Census data.	Based on our literature review on the effect of water quality impacts on property values, we identified these studies as the best available that relate property value with a water quality indicator present in the model (Secchi depth). While other studies are available that relate property value to other water quality indicators, such as fecal coliform concentration, these indicators are not present in the model.	MEDIUM: The estimates of the effect of water clarify on property value are not specific to Narragansett Bay. In addition, because property value data from the Census is self-reported by owners of owner-occupied structures, the values may be somewhat overstated. Conversely, the exclusion of non-owner occupied structures from this data set, likely results in an underestimate of aggregate property value within the block groups. In addition, note that commercial properties are not included in this relationship, which also results in an underestimate of total property value impacts.
GDP	(1) Bureau of Economic Analysis (BEA), US Regional Economic Information System; (2) Labor income: BEA state personal income (SPI) accounts. (3) Non-corporate capital income: BEA's SPI accounts. (4) Business taxes and subsidies paid to business by government: Census Bureau, other federal agencies, and state government agencies	GDP is used to determine investment in the economy (allocated to agriculture, industry and services), public budget (revenues and expenditure) as well as energy consumption. GDP is also used as an output indicator, being affected by nitrogen loadings through the performance of the fishery and tourism sectors.	GDP by state is the state counterpart of the Nation's gross domestic product (GDP). GDP by state is derived as the sum of the GDP originating in all the industries in a state. As such, RI data were chosen as they better resemble Narragansett Bay's economic structure than MA data.	MEDIUM: While Narragansett Bay has an economic structure similar to the one of Rhode Island, it would be beneficial to fully disaggregate economic activity by State and county, and assess only the performance of the economic activities of the bay.
Per Capita Disposable Income	(1) BEA, US Regional Economic Information System; (2) Wage and salaries: North American Industry Classification System (NAICS). (3) Population: BEA Census Bureau's annual midyear (July 1) population estimates.	Primarily an output indicator, it is used to assess the potential impact of nitrogen reduction investments on consumption and savings. Per capita income is also used to estimate household consumption, investment and savings (i.e. households' contribution to the economy - from a demand-side perspective).	The BEA generates data primarily based on GDP and income. These databases are widely used and generally considered the most reliable for economic analysis at the state level.	MEDIUM: Same as for GDP. While the quality of data is high, more disaggregated information would fit better the specific context of Narragansett Bay.

Energy Use	(1) U.S. Energy Information Administration (EIA), U.S. Department of Energy. (2) State Energy Data System (SEDS), divided into several EIA databases, by sector and energy source.	Energy consumption is primarily used to estimate air emissions and nitrogen atmospheric deposition. This metric includes changes in energy consumption at waste water treatment facilities related to different nitrogen removal processes.	The SEDS is the source of the U.S. EIA state energy statistics. The database includes energy production, consumption, prices, and expenditures by state that are defined as consistently as possible over time and across sectors for analysis and forecasting purposes.	MEDIUM: The quality of the data is excellent, but is not specific to Narragansett Bay. Given that the energy consumption patterns are likely similar for both RI and MA in relation to the bay, we believe that lack of Bay specific data is acceptable in this case
Effect of Open Space on Property Values	(1) Mazzotta, Marisa., Atlantic (Ecology Division, U.S. EPA. 2013. Personal communication, including “Meta Analysis results and variable assignments” document, on June 11	EPA’s meta-analysis provided regression parameters that relate changes in open space to changes in property values for both existing residential units and new residential units. We assumed that implementing LID/GI would increase the amount of open space around residential units. For the two Use Case areas (Providence and Taunton), we created a relationship between LID/GI implementation and increases in residential property value.	EPA’s meta-analysis looked at multiple published studies examining the relationship between different types of open space and property values. Because LID/GI generally results in more open space than traditional development, we were able to use this analysis to relate LID/GI to property values.	LOW: While the meta-analysis synthesizes the results of multiple published analyses of the impact of open space on property values, we made a number of simplifying assumptions in order to incorporate the meta-analysis regression parameters into the model. These assumptions include how much open space would be created by LID/GI implementation and what percentage of existing residential units would be affected by LID/GI implemented around new units.

EXHIBIT 4-5. CHARACTERIZATION OF CONFIDENCE LEVELS FOR MODEL INDICATORS

INDICATOR NAME	MODEL INPUTS[1]	CONFIDENCE LEVEL	SUMMARY OF DATA INPUTS (COUNTS OF INPUTS BY LEVEL OF CONFIDENCE)[2]			
			HIGH	MEDIUM	LOW	UNKNOWN
SOCIAL AND ECONOMIC INDICATORS						
General						
Municipal tax revenue (related to changes in property values)			9	12	3	4
	Property tax rates	*High*	1			1
	Property value	*See "Property value"*	8	12	3	3
Per-capita disposable income	*Per-capita disposable income*	*Medium*		1		
Property value			8	12	3	3
	Water turbidity / clarity	*See "Water turbidity / clarity"*	8	11	2	3
	Effect of water clarity on property value	*Medium*		1		
	Effect of open space on property values	*Low*			1	
GDP (change relative to baseline)	*GDP*	*Medium*		1		
Natural Resource Revenue						
Commercial finfish landings			7	8	3	3
	Effect of nitrogen on finfish landings	*Low*			1	
	Total nitrogen loadings	*See "Total nitrogen loadings"*	7	8	2	3
Aquaculture revenue	*Aquaculture revenue*	*Medium*		1		
Employment in aquaculture	*Employment in aquaculture*	*Medium*		1		
Recreation and Tourism						
Beach visits			8	12	2	0
	Effect of water clarity on beach visits	*Medium*		1		

	Water turbidity / clarity	*See "Water turbidity / clarity"*	8	11	2	
Consumer surplus from beach visits			8	12	2	1
	Consumer surplus per beach visit	*Medium*				1
	Beach visits	*See "Beach visits"*	8	12	2	
Nitrogen removal costs						
Cost of N reduction from improvements to ISDSs or from WWTF treatment	*User input (with default value)*	*Low (for default values)*	1			
WWTF energy consumption	*Energy use*	*Medium*		1		
Cost of N reductions from residential fertilizer, agricultural fertilizer, and animal waste	*User input*	*N/A*				
Cost of N reductions from LID/GI retrofits	*User input (with default cost curve)*	*Low (for default values)*	1			
Cost of N reductions from aquaculture	*Annual aquaculture operating costs*	*Medium*		1		
ENVIRONMENTAL INDICATORS						
Nitrogen loadings						
Total nitrogen loadings			7	8	2	3
Nitrogen loadings from ISDSs/septics			2	2	1	0
	*Spatial disaggregation of nitrogen loadings**	*Medium*		1		
	*Seasonal distribution of nitrogen loadings**	*Low*			1	
	N loadings from ISDS	*Medium*		1		
	Drivers affecting N loadings over time	*High*	1			
	Population	*High*	1			
Nitrogen loadings from WWTFs			5	0	0	0
	Spatial disaggregation of nitrogen loadings	*High*	1			
	Seasonal distribution of nitrogen loadings	*High*	1			
	Drivers affecting N loadings over time	*High*	1			

	2000-2014 N loadings from WWTFs	*High*	1			
	Population	*High*	1			
Nitrogen loadings from residential fertilizer			2	4	2	0
	Spatial disaggregation of nitrogen loadings	*Low*			1	
	Seasonal distribution of nitrogen loadings	*Low*			1	
	Relationship between population and N loadings from residential fertilizer	*Medium*		1		
	Population	*High*	1			
	Drivers affecting N loadings over time	*High*	1			
	Method for estimating N loadings from surface water runoff	*Medium*		1		
	Imperviousness	*Medium*		1		
	Precipitation (future projections)	*Medium*		1		
Nitrogen loadings from agricultural fertilizer			3	1	1	0
	Spatial disaggregation of nitrogen loadings	*High*	1			
	Seasonal distribution of nitrogen loadings	*Low*			1	
	2002 N loadings from agricultural fertilizer	*High*	1			
	Drivers affecting N loadings over time	*High*	1			
	Precipitation (future projections)	*Medium*		1		
Nitrogen loadings from animal waste			3	1	1	0
	Spatial disaggregation of nitrogen loadings	*High*	1			
	Seasonal distribution of nitrogen loadings	*Low*			1	
	2002 N loadings from animal waste	*High*	1			
	Drivers affecting N loadings over time	*High*	1			
	Precipitation (future projections)	*Medium*		1		

Nitrogen loadings from direct atmospheric deposition			2	3	1	2
	Spatial disaggregation of nitrogen loadings	*High*	1			
	Seasonal distribution of nitrogen loadings	*Low*			1	
	Atmospheric deposition (future projections)	*Medium*		1		
	Energy use	*Medium*				
	Relationship between population and GDP and energy use	*Unknown (from T21 model)*				1
	Relationship between energy use and atmospheric deposition	*Unknown (from T21 model)*				1
	Precipitation (future projections)	*Medium*		1		
	Population	*High*	1			
	GDP	*Medium*		1		
Nitrogen loadings from impervious surfaces			3	5	1	1
	Spatial disaggregation of nitrogen loadings	*Medium*		1		
	Seasonal distribution of nitrogen loadings	*Low*			1	
	2002 nitrogen loadings from atmospheric deposition on the watershed	*High*	1			
	Drivers affecting N loadings over time	*High*	1			
	Method for estimating N loadings from surface water runoff	*Medium*		1		
	Imperviousness	*Medium*		1		
	Atmospheric deposition (future projections)	*Medium*		1		
	Precipitation (future projections)	*Medium*		1		
	Population	*High*	1			
	Relationship between population and developed land	*Unknown (from T21 model)*				1

Nitrogen loadings from natural surfaces			3	5	1	1
	Spatial disaggregation of nitrogen loadings	*Medium*		1		
	Seasonal distribution of nitrogen loadings	*Low*			1	
	2002 nitrogen loadings from atmospheric deposition on the watershed	*High*	1			
	Drivers affecting N loadings over time	*High*	1			
	Method for estimating N loadings from surface water runoff	*Medium*		1		
	Imperviousness	*Medium*		1		
	Atmospheric deposition (future projections)	*Medium*		1		
	Precipitation (future projections)	*Medium*		1		
	Population	*High*	1			
	Relationship between population and developed land	*Unknown (from T21 model)*				1
Nitrogen loadings from other urban stormwater			0	0	3	0
	Spatial disaggregation of nitrogen loadings	*Low*			1	
	Seasonal distribution of nitrogen loadings	*Low*			1	
	N loadings from other urban stormwater	*Low*			1	
Water quality						
Nitrogen concentration			7	10	2	3
	Total nitrogen loadings	*See "Total nitrogen loadings"*	7	8	2	3
	Nitrogen circulation in the bay	*Medium*		1		
	Nitrogen losses in the bay (30 percent per year)	*Medium*		1		
Chlorophyll a concentration / macro-algal blooms			8	10	2	3

	Effect of nitrogen loading on chlorophyll	*High*	1			
	Nitrogen concentration	*See "Nitrogen Concentration"*	7	10	2	3
Hypoxia risk	*Hypoxia risk*	*Low*			1	
Ulva growth rate			7	11	2	3
	Effect of nitrogen loading on relative sea lettuce (ulva) growth rate	*Medium*		1		
	Nitrogen concentration	*See "Nitrogen Concentration"*	7	10	2	3
Eelgrass improvement potential	*Eelgrass improvement potential*	*Low*			1	
Water turbidity / clarity			8	11	2	3
	Effect of micro algae (chlorophyll a) on secchi depth	*Medium*		1		
	Chlorophyll a concentration / macro-algal blooms	*See "Chlorophyll A concentration"*	8	10	2	3
Other						
Precipitation	*Precipitation future projections*	*Medium*		1		

Notes:

1. Spatial disaggregation of nitrogen loadings' and 'Seasonal disaggregation of nitrogen loadings serve as inputs for multiple loadings categories, and the confidence level for these inputs varies across N loadings categories.
2. Some inputs (e.g., population and precipitation) serve as inputs for multiple subcategories (e.g., nitrogen loadings from residential fertilizer), but they are only counted once for larger categories (e.g., total nitrogen loadings).

VALIDATION OF HISTORICAL SIMULATIONS

The calibration of the model starts with the evaluation of the results generated using specific parameters or equations obtained from literature. This is accomplished through the comparison of historical data and the results of the baseline simulation.

The example provided below shows the Narragansett 3VS model baseline simulation (blue line) and historical data (red line) for the period 1990 – 2012. The model starts simulating in 1990, and runs differential equations to project results for subsequent years; it does not use historical data to generate projections. Therefore, we were able to use historical data to check whether the structure of the model is capable of reproducing the historical observed behavior.

Population

Exhibit 4-6 compares modeled values for total population to data from NOAA's STICS database. The R^2 for the modeled and observed population values is 0.97. The stock of population in the model is driven by fertility, mortality and migration, with the latter set as an exogenous input. Population is disaggregated by gender and subwatershed area, into upshed and bayside population for WWTF nitrogen loadings, and into sewered and unsewered population for Rohde Island and Massachusetts in the case of ISDS nitrogen loadings.

Nitrogen Loadings

We compare the model's estimates of nitrogen loadings to a time series data that based on the VHP model and SPARROW, described in Section 2-6. In the model, we used the VHP study as a key source of information to obtain an estimation of medium to longer-term trends, but the absolute number for nitrogen loadings was corrected (lowered) using primarily SPARROW estimates, among others.

The top graph in Exhibit 4-7 compares the Narragansett 3VS model's baseline simulation to a time series based solely on the VHP model's estimates. While the absolute value of nitrogen loadings is different, the trend of the two time series is similar. This is confirmed by the bottom graph, where the VHP-derived time series is lowered to match the 3VS model's estimation for the year 2000, which were calibrated to match total nitrogen loadings estimated by the SPARROW model (with the exception of loadings sources that discharge directly to the bay, such as bayside WWTFs and direct atmospheric deposition). This comparison yields an R^2 of 0.40 and an average annual deviation of five percent.

EXHIBIT 4-6. BASELINE SIMULATION AND HISTORICAL DATA FOR POPULATION

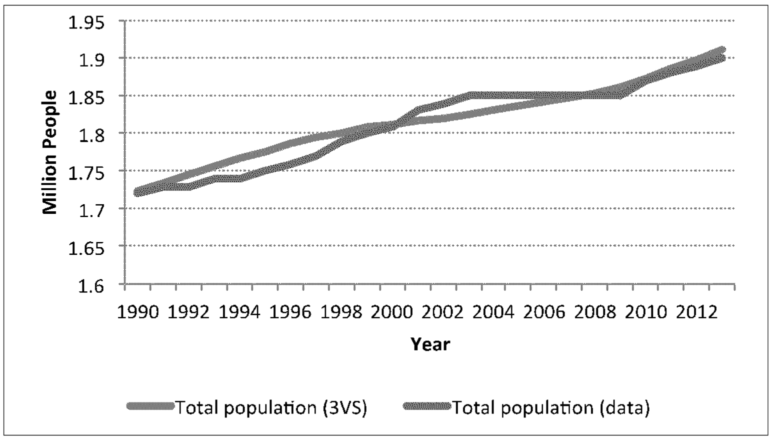
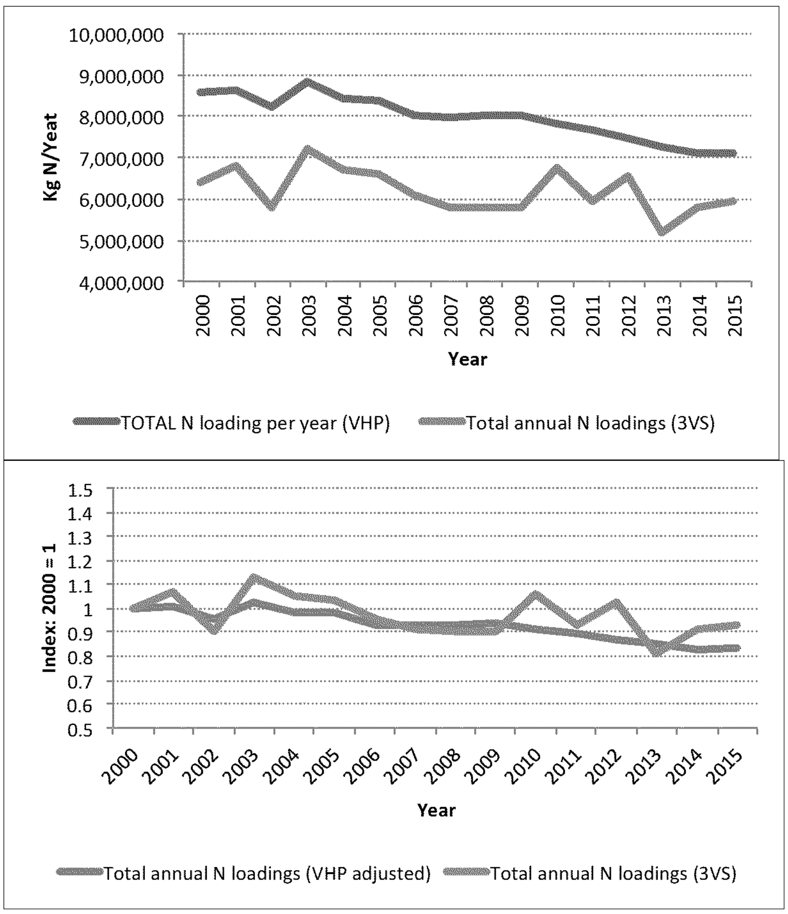
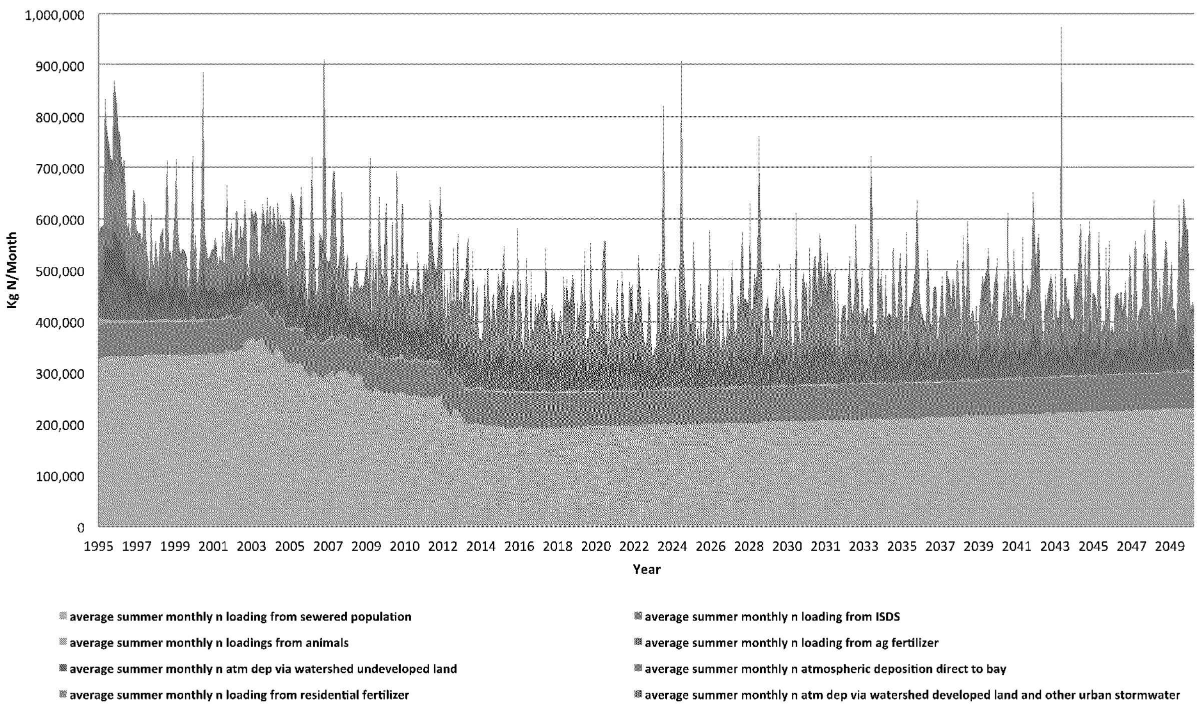


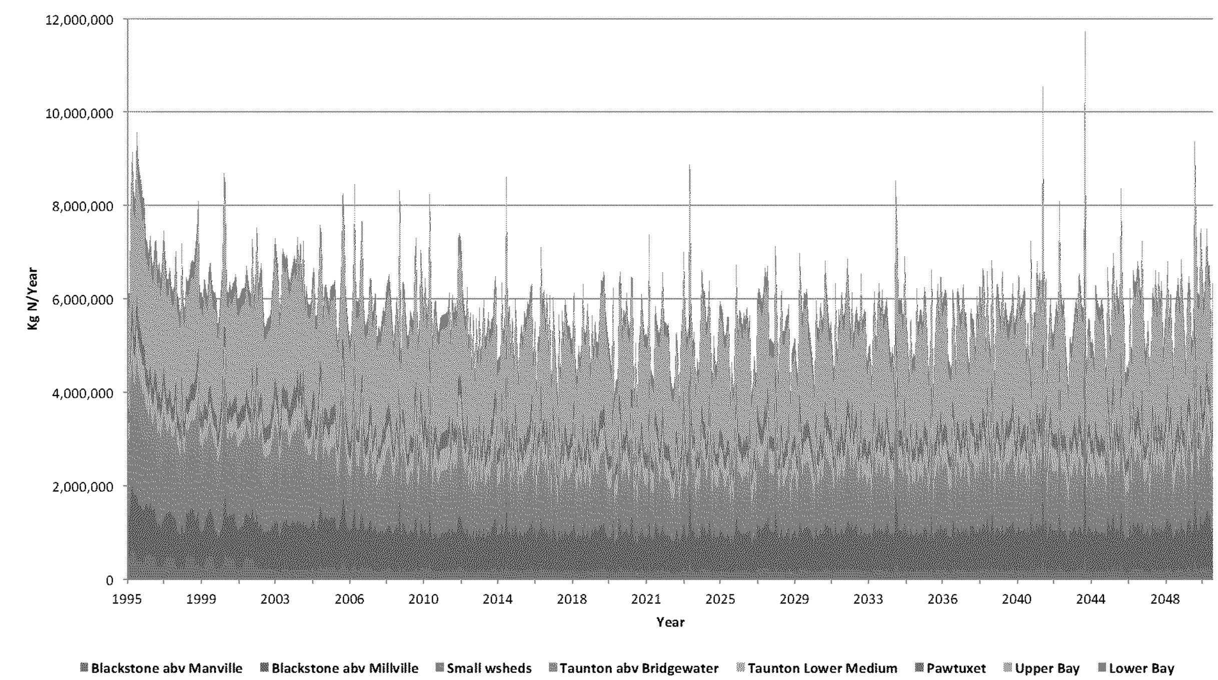
EXHIBIT 4-7. BASELINE SIMULATION AND HISTORICAL DATA FOR NITROGEN LOADINGS, VHP-DERIVED AND 3VS (TOP GRAPH), AND ADJUSTED VHP-DERIVED AND 3VS, RELATIVE TO 2000 3VS LOADINGS (BOTTOM GRAPH)

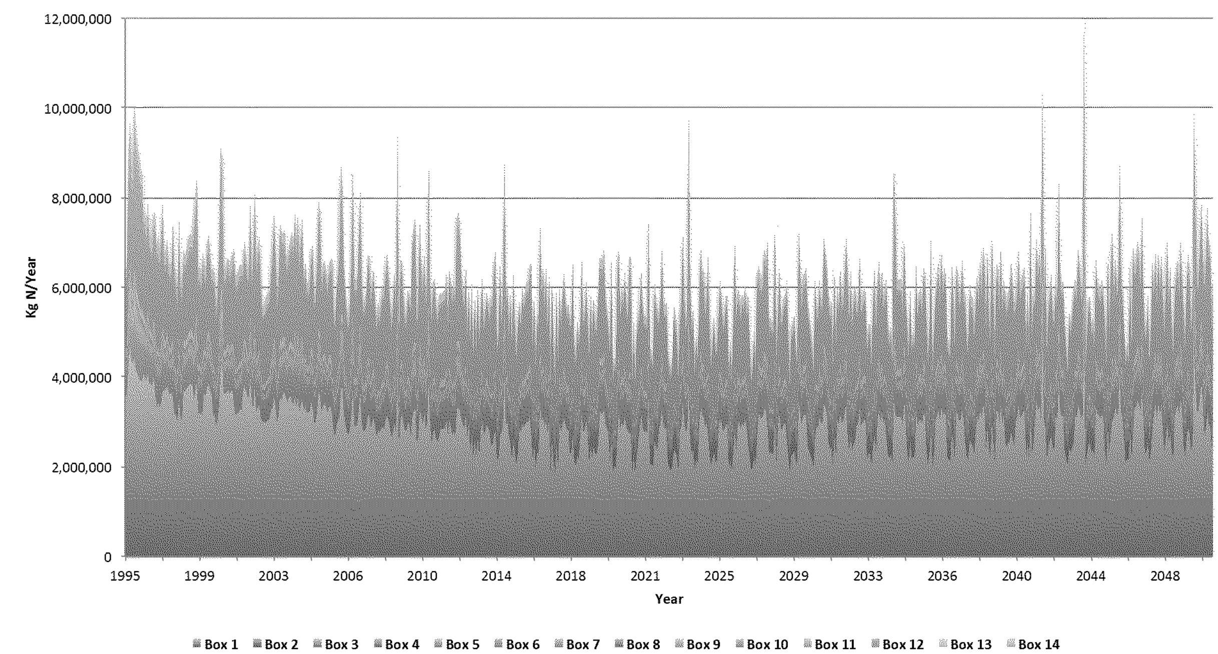


We also calibrated nitrogen loadings in the model at a higher degree of disaggregation, considering (1) different sources of loadings, (2) subwatershed areas, and (3) bay boxes (See Exhibit 4-8 for an illustration of loadings disaggregated by source, subwatershed area, and bay box). The calibration was considered complete when the margin of error (measured as an average point to point error) was within acceptable boundaries. For example, in the case of nitrogen loadings, we have compared the model's estimates of loadings in 2002 with estimates from other sources, including SPARROW, EPA's Community Multi-Scale Air Quality (CMAQ) model, and others. For aggregate or bay-wide loadings, values within five percent of SPARROW are considered good, those within 15 percent are considered medium, and those within 30 percent are considered poor. We did not apply the same error boundaries for higher degrees of disaggregation, as we expected that the model's fit may not be as tight at these levels. The main reason for the lower degree of accuracy for disaggregated variables is that the structure of the model includes drivers for aggregated variables (which are then disaggregated), rather than specific drivers for the disaggregated variables. The Narragansett 3VS model was built to capture macro trends over the medium and longer term; hence consistency across dimensions and sectors was given priority over the level of detail and accuracy of results with a high degree of disaggregation.

EXHIBIT 4-8. BASELINE SIMULATION FOR NITROGEN LOADINGS BY SOURCE (TOP GRAPH), BY SUBWATERSHED AREA (MIDDLE GRAPH) AND BY BAY BOX (BOTTOM GRAPH)




12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
Kg N/Year
1995
1999
2003
2006
2010
2014
2018
2021
2025
2029
2033
2036
2040
2044
2048
Year
Blackstone abv Manville
Blackstone abv Millville
Small wsheds
Taunton abv Bridgewater
Taunton Lower Medium
Pawtuxet
Upper Bay
Lower Bay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2048
Year
Box 1
Box 2
Box 3
Box 4
Box 5
Box 6
Box 7
Box 8
Box 9
Box 10
Box 11
Box 12
Box 13
Box 14

Exhibits 4-9, 4-10 and 4-11 compare the results of the baseline simulation to independent loadings estimates for 2002. As described in the "Nitrogen Loadings" section of Exhibit 4-1, loadings estimates for 2002 for WWTF are based on facility-level compliance and monitoring data; loadings estimates for atmospheric deposition (undeveloped land), agricultural fertilizer, and animals are based on SPARROW data; loadings estimates for residential fertilizer are based on fertilizer sales data; loadings estimates for atmospheric deposition on the watershed and other urban stormwater are based on the simple method for calculating pollution from surface water runoff on developed land; loadings estimates for ISDS are based on VHP loadings parameters and geographic analysis of soil types; and loadings estimates for atmospheric deposition direct to the bay are based on CMAQ. Each Exhibit includes three tables: the first table in each exhibit presents the 2002 data, the second presents the Narragansett 3VS model's projections, and the third presents a comparison of the two. More specifically, the values included in the third table are calculated as the ratio of Narragansett 3VS model results to the 2002 data. As an example, a value of 110 percent in the third table would indicate that the 3VS simulation is 10 percent higher than the 2002 data.

Each table includes total nitrogen loadings in the rightmost column. In Exhibit 4-9, the other columns present loadings disaggregated by subwatershed area, while in Exhibit 4-10, the other columns present loadings disaggregated by bay box. In Exhibit 4-10, loadings are presented disaggregated by source and season.

EXHIBIT 4-9. COMPARISON OF BASELINE SIMULATION NITROGEN LOADINGS BY SOURCE AND SUBWATERSHED AREA (KG N/YEAR): INDEPENDENT ESTIMATES (TOP TABLE), NARRAGANSETT 3VS PROJECTIONS (MIDDLE TABLE), AND RATIO BETWEEN THE TWO (BOTTOM TABLE).

	Combined Loadings (kg N)										
			Surface Water Runoff								
	WWTF		Undeveloped Land			Developed Land					
VHP Subwatershed Area	Upshed WWTF	Bayside WWTF	Atmospheric Deposition	Agricultural Fertilizer	Animals	Atmospheric Deposition	Residential Fertilizer	Other Urban Stormwater	ISDS	Atmospheric Deposition Direct to Bay	Total Loadings
Blackstone_abv_Manville	125,293	0	17,170	10,350	2,016	2,734	14,836	9,851	42,936	n/a	225,185
Blackstone_abv_Millville	478,567	0	53,002	37,260	7,257	18,651	53,411	35,465	183,943	n/a	867,555
Lower_Bay	0	195,074	19,364	15,007	2,923	9,496	21,512	14,284	72,737	n/a	350,396
Pawtuxet	187,728	0	18,734	11,144	2,171	2,697	15,975	10,607	67,803	n/a	316,859
Small_wsheds	194,923	507,485	56,691	45,267	8,817	30,360	64,889	43,086	119,742	n/a	1,071,258
Taunton_abv_Bridgewater	514,322	0	45,428	32,354	6,302	16,790	46,378	30,795	81,263	n/a	773,632
Taunton_Lower_Mid	181,329	0	37,244	26,632	5,187	13,970	38,176	25,349	79,389	n/a	407,276
Upper_Bay	396,180	1,363,825	52,705	59,754	11,638	62,204	85,655	56,875	127,064	n/a	2,215,901
Total	2,078,342	2,066,384	300,339	237,766	46,310	156,901	340,833	226,311	774,877	290,057	6,518,120

* Distributed according to the % of Total Stormwater Loadings in each SPARROW category (note that all VHP subwatershed areas are treated the same way)

	Combined Loadings (kg N)										
			Surface Water Runoff								
	WWTF		Undeveloped Land			Developed Land					
VHP Subwatershed Area	Upshed WWTF	Bayside WWTF	Atmospheric Deposition	Agricultural Fertilizer	Animals	Atmospheric Deposition	Residential Fertilizer	Other Urban Stormwater	ISDS	Atmospheric Deposition Direct to Bay	Total Loadings
Blackstone_abv_Manville	106,171	0	17,089	8,442	1,647	2,690	13,739	18,471	42,934	n/a	211,183
Blackstone_abv_Millville	527,502	0	52,730	38,323	7,547	18,209	55,773	34,911	184,286	n/a	919,280
Lower_Bay	0	179,933	19,270	14,998	2,964	9,298	22,245	3,462	72,765	n/a	324,935
Pawtuxet	231,847	0	18,642	13,473	2,840	2,574	20,555	9,265	67,815	n/a	367,011
Small_wsheds	235,588	501,500	56,404	42,952	8,341	29,566	58,798	33,438	119,778	n/a	1,086,364
Taunton_abv_Bridgewater	484,102	0	45,201	26,380	5,588	16,272	47,251	40,348	81,284	n/a	746,426
Taunton_Lower_Mid	203,303	0	37,045	29,462	5,836	13,547	28,772	25,711	79,544	n/a	423,220
Upper_Bay	466,719	1,453,462	52,431	56,262	11,121	60,785	90,545	18,640	127,065	n/a	2,337,029
Total	2,255,232	2,060,077	298,812	230,292	45,883	152,940	337,677	184,245	775,470	276,151	6,616,780

	Combined Loadings (kg N)										
			Surface Water Runoff								
	WWTF		Undeveloped Land			Developed Land					
VHP Subwatershed Area	Upshed WWTF	Bayside WWTF	Atmospheric Deposition	Agricultural Fertilizer	Animals	Atmospheric Deposition	Residential Fertilizer	Other Urban Stormwater	ISDS	Atmospheric Deposition Direct to Bay	Total Loadings
Blackstone_abv_Manville	85%		100%	82%	82%	98%	93%	188%	100%		94%
Blackstone_abv_Millville	110%		99%	103%	104%	98%	104%	98%	100%		106%
Lower_Bay		92%	100%	100%	101%	98%	103%	24%	100%		93%
Pawtuxet	124%		100%	121%	131%	95%	129%	87%	100%		116%
Small_wsheds	121%	99%	99%	95%	95%	97%	91%	78%	100%		101%
Taunton_abv_Bridgewater	94%		100%	82%	89%	97%	102%	131%	100%		96%
Taunton_Lower_Mid	112%		99%	111%	113%	97%	75%	101%	100%		104%
Upper_Bay	118%	107%	99%	94%	96%	98%	106%	33%	100%		105%
Total	109%	100%	99%	97%	99%	97%	99%	81%	100%	95%	102%

EXHIBIT 4-10. COMPARISON OF BASELINE SIMULATION NITROGEN LOADINGS BY SOURCE AND BAY BOX (KG N/YEAR): INDEPENDENT ESTIMATES (TOP TABLE), NARRAGANSETT 3VS PROJECTIONS (MIDDLE TABLE), AND RATIO BETWEEN THE TWO (BOTTOM TABLE)

Bay Box	Combined Loadings (kg N)									
	WWTF	Surface Water Runoff					ISDS	Atmospheric Deposition Direct to Bay	Total Loadings
		Undeveloped Land			Developed Land				
		Atmospheric Deposition	Agricultural Fertilizer	Animals	Atmospheric Deposition + Other Urban Stormwater	Residential Fertilizer			
1	2,350,932	127,405	69,410	18,594	132,315	97,525	340,829	6,920	3,143,931
2	316,981	52,493	16,362	5,096	49,525	40,427	135,836	9,191	625,912
3	0	492	323	90	8,495	7,905	372	20,696	38,373
4	0	0	0	0	1,724	2,596	143	13,524	17,987
5	33,580	12,817	20,683	3,975	20,558	21,944	12,185	18,177	143,919
6	13,477	881	491	76	7,999	7,370	5,920	5,965	42,180
7	0	146	23	5	6,951	9,692	5,920	8,638	31,376
8	0	4,221	1,791	244	14,501	17,290	44,740	31,262	114,049
9	96,220	325	221	53	5,195	7,073	1,303	31,929	142,319
10	1,138,462	97,776	122,974	17,247	113,550	100,662	178,647	47,082	1,816,400
11	11,566	2,368	2,486	223	5,561	5,590	21,340	37,766	86,902
12	0	849	2,645	619	4,516	4,963	2,237	28,781	44,610
13	0	475	357	88	10,238	14,923	24,326	12,771	63,179
14	183,508	91	0	0	2,083	2,871	1,077	17,354	206,984
Total	4,144,726	300,339	237,766	46,310	383,212	340,833	774,877	290,057	6,518,120

Bay Box	Combined Loadings (kg N)									
	WWTF	Surface Water Runoff					ISDS	Atmospheric Deposition Direct to Bay	Total Loadings
		Undeveloped Land			Developed Land				
		Atmospheric Deposition	Agricultural Fertilizer	Animals	Atmospheric Deposition + Other Urban Stormwater	Residential Fertilizer			
1	2,522,923	126,756	67,222	18,422	120,189	120,352	337,557	6,600	3,320,021
2	341,297	52,232	15,844	5,047	42,572	42,630	103,775	8,754	612,150
3	0	478	322	92	3,856	3,861	635	19,717	28,961
4	0	0	0	0	939	940	254	12,869	15,002
5	36,483	12,759	20,035	3,937	18,927	18,953	24,942	17,315	153,352
6	15,361	867	484	73	3,744	3,749	5,464	5,689	35,431
7	0	149	23	5	3,744	3,749	5,464	8,229	21,364
8	0	4,213	1,727	243	8,308	8,319	41,301	29,769	93,881
9	132,492	329	207	55	2,825	2,829	1,526	30,404	170,668
10	1,159,923	97,293	119,107	17,087	119,116	119,278	200,599	44,819	1,877,222
11	14,161	2,361	2,418	220	3,470	3,474	25,249	35,955	87,308
12	0	837	2,556	615	2,889	2,893	1,854	27,394	39,037
13	0	478	345	87	5,566	5,574	26,195	12,151	50,396
14	165,773	90	0	0	1,074	1,076	582	16,514	185,109
Total	**4,388,413**	**298,842**	**230,292**	**45,883**	**337,218**	**337,677**	**775,398**	**276,178**	**6,689,902**

Bay Box	Combined Loadings (kg N)									
	WWTF	Surface Water Runoff					ISDS	Atmospheric Deposition Direct to Bay	Total Loadings
		Undeveloped Land			Developed Land				
		Atmospheric Deposition	Agricultural Fertilizer	Animals	Atmospheric Deposition + Other Urban Stormwater	Residential Fertilizer			
1	107%	99%	97%	99%	91%	123%	99%	95%	106%
2	108%	100%	97%	99%	86%	105%	76%	95%	98%
3		97%	100%	102%	45%	49%	171%	95%	75%
4					54%	36%	178%	95%	83%
5	109%	100%	97%	99%	92%	86%	205%	95%	107%
6	114%	98%	99%	96%	47%	51%	92%	95%	84%
7		102%	100%	84%	54%	39%	92%	95%	68%
8		100%	96%	100%	57%	48%	92%	95%	82%
9	138%	101%	94%	103%	54%	40%	117%	95%	120%
10	102%	100%	97%	99%	105%	118%	112%	95%	103%
11	122%	100%	97%	99%	62%	62%	118%	95%	100%
12		99%	97%	99%	64%	58%	83%	95%	88%
13		101%	97%	99%	54%	37%	108%	95%	80%
14	90%	98%			52%	37%	54%	95%	89%
Total	106%	100%	97%	99%	88%	99%	100%	95%	103%

EXHIBIT 4-11. COMPARISON OF BASELINE SIMULATION NITROGEN LOADINGS BY SOURCE AND SEASON (KG N/YEAR): INDEPENDENT ESTIMATES (TOP TABLE), NARRAGANSETT 3VS PROJECTIONS (MIDDLE TABLE), AND RATIO BETWEEN THE TWO (BOTTOM TABLE)

Loadings Category	Seasonal Variation?	Percent in Summer	Data Source	2002 Nitrogen Loadings (kg)		
				Summer	Winter	Total
WWTF	Yes	Facility-specific	DMR data	2,100,353	2,018,304	4,118,657
ISDS	No	50.4%	Default	390,623	384,254	774,877
Atm. Deposition (undeveloped land)	No	50.4%	Default	151,404	148,935	300,339
Agricultural Fertilizer	Yes	80%	Baseline assumption	190,213	47,553	237,766
Animals	No	50.4%	Default	23,345	22,965	46,310
Atm. Deposition (developed land)	No	50.4%	Default	79,095	77,806	156,901
Residential Fertilizer	Yes	80%	Baseline assumption	272,666	68,167	340,833
Other Urban Stormwater	No	50.4%	Default	114,086	112,226	226,311
Atm. Deposition (direct to the bay)	No	50.4%	Default	146,220	143,836	290,057
Subtotal (all runoff categories)	*Yes (partial)*	***63.5%***	*Calculated*	*830,809*	*477,651*	*1,308,460*
Total				**3,468,006**	**3,024,045**	**6,492,051**

Days in Summer (May 1st - Oct 31st)	184
Share of total days in a year	50.4%

Loadings Category	Seasonal Variation?	Percent in Summer	Data Source	2002 Nitrogen Loadings (kg)		
				Summer	Winter	Total
WWTF	Yes	Facility-specific	Model	2,198,492	2,116,817	**4,315,309**
ISDS	No	50.4%	Model	390,922	384,548	**775,470**
Atm. Deposition (undeveloped land)	No	50.4%	Model	150,634	148,178	**298,812**
Agricultural Fertilizer	Yes	80%	Model	184,234	46,058	**230,292**
Animals	No	50.4%	Model	23,130	22,753	**45,883**
Atm. Deposition (developed land)	No	50.4%	Model	77,099	75,842	**152,940**
Residential Fertilizer	Yes	80%	Model	270,141	67,535	**337,677**
Other Urban Stormwater	No	50.4%	Model	92,880	91,366	**184,245**
Atm. Deposition (direct to the bay)	No	50.4%	Model	139,210	136,940	**276,151**
Subtotal (all runoff categories)	*Yes (partial)*	***63.5%***	*Model*	*824,117*	*477,306*	*1,249,850*
Total				**3,526,742**	**3,081,658**	**6,616,780**

Loadings Category	Seasonal Variation?	Percent in Summer	Data Source	2002 Nitrogen Loadings (kg)		
				Summer	Winter	Total
Upshed WWTF	Yes	Facility-specific	Model	96%	95%	**95%**
ISDS	No	50.4%	Model	100%	100%	**100%**
Atm. Deposition (undeveloped land)	No	50.4%	Model	101%	101%	**101%**
Agricultural Fertilizer	Yes	80%	Model	103%	103%	**103%**
Animals	No	50.4%	Model	101%	101%	**101%**
Atm. Deposition (developed land)	No	50.4%	Model	103%	103%	**103%**
Residential Fertilizer	Yes	80%	Model	101%	101%	**101%**
Other Urban Stormwater	No	50.4%	Model	123%	123%	**123%**
Atm. Deposition (direct to the bay)	No	50.4%	Model	105%	105%	**105%**
Subtotal (all runoff categories)	*Yes (partial)*	***63.5%***	*Model*	*101%*	*100%*	*105%*
Total				**98%**	**98%**	**98%**

Exhibit 4-9 shows that total nitrogen loadings by source category fit the 2002 data well, with an average error within two percent (see for instance nitrogen loadings from agricultural fertilizer: 97 percent, indicating that the model is projecting values three percent below the 2002 data). Total nitrogen loadings by subwatershed area also match the data well, with the highest error being recorded for Pawtuxet at 16 percent. All the other areas are within 10 percent, with Upper Bay and Small Watersheds, the two largest areas in relation to loadings, recording a five percent and one percent discrepancy with data, respectively.

The errors become larger when considering disaggregated loadings by source for specific subwatershed areas. This is due primarily to the lack of information on specific assumptions that are applied for each loadings category across all subwatershed areas equally (e.g. residential fertilizer use per ha, and nitrogen loadings per animal). In addition, the nitrogen loading source "other urban stormwater" is calculated as a residual factor of nitrogen loadings from runoff, and therefore includes the discrepancies embedded in the other sources of nitrogen loadings estimated endogenously.

Exhibit 4-10 shows the same disaggregation of nitrogen loadings by source, but it considers bay boxes rather than subwatershed areas. As noted earlier, the fit for total loadings by source is better than the fit for total loadings by box. In this case, 13 out of 14 boxes are within the 30 percent error threshold (with the exception of Box 7), and only four boxes record an average error at 20 percent or above (Boxes 3, 7, 9 and 13). It should be noted that while nitrogen loadings are estimated for Boxes 6 and 7, these are aggregated into a single value (Greenwich Bay -GB-) for the estimation of nitrogen concentration.

Higher discrepancies between the simulation and historical data are observed when considering specific nitrogen loading sources for specific bay boxes. This is primarily due to the method used, and the information available, to estimate nitrogen loadings by bay box. In general, the model estimates loadings by subwatershed area and then translates those estimates into loadings by box based on the percent of each box's watershed in each subwatershed area. An example of the equations used for this process is presented here, and more details are available in Section 2-6:

- *N Loading From Sewered Population By Box[**BOX2**]=*
  *"WWTF: total annual N loadings by subwatershed loading area" [PAWTUXET]*1*
  *+ "WWTF: total annual N loadings by subwatershed loading area" [UPPER BAY]*0.057*

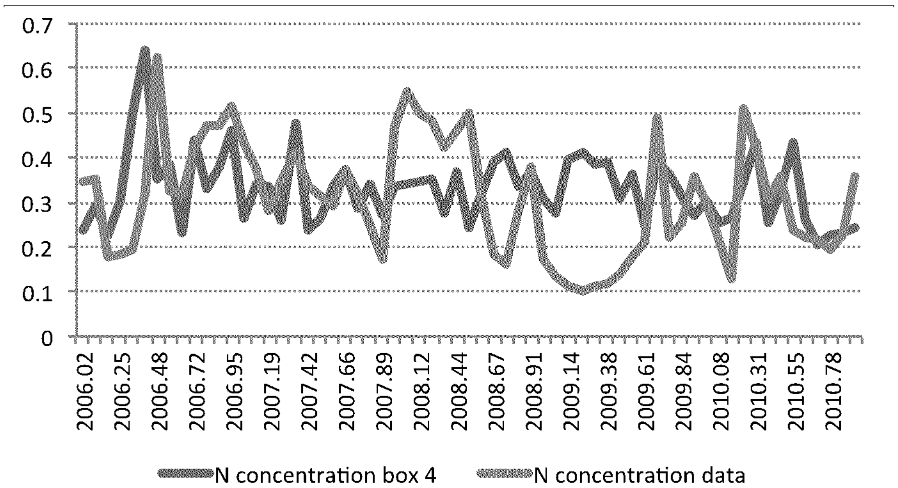
This equation indicates that 100 percent of the loadings from sewered population in Pawtuxet and 5.7 percent of the loadings from Upper Bay should be allocated to Box 2. Because the parameters that drive nitrogen loadings (e.g., sewered and unsewered population, acreage of impervious cover, acreage of cropland) are not evenly distributed across subwatershed areas or box-watersheds, this method of estimating loadings by box introduces an added degree of imprecision at the bay box level.

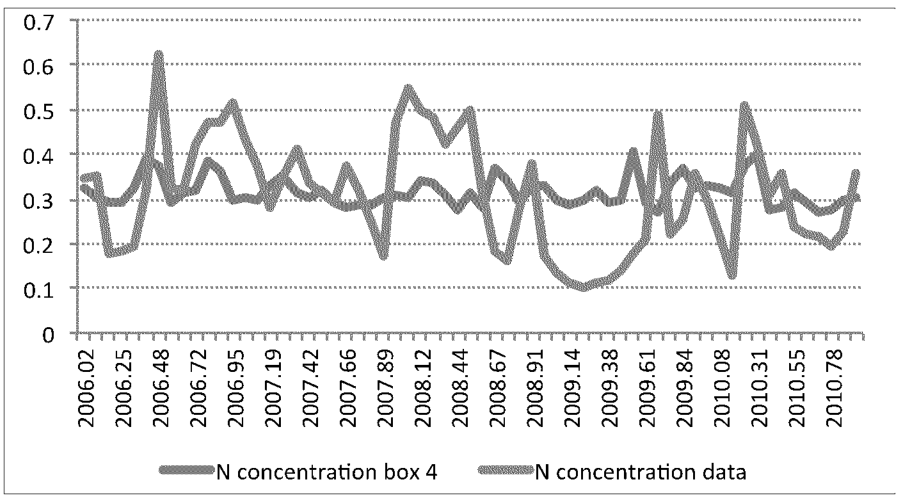
Nitrogen loadings are projected taking into account seasonal variations. The sources of nitrogen loadings affected by seasonality are WWTF and fertilizer (both agriculture and residential). The seasonal variation from WWTF is policy-driven, with effluent limits being enforced in summer months, while the variation in fertilizer loadings is driven by differences in seasonal fertilizer use. The seasonal variation is introduced in the model for summer and winter only (i.e. there is no monthly variation, only a seasonal one) using an "if then else" function. Different data inputs (e.g., per-capita summer vs. winter WWTF loadings) or multipliers (e.g. share of agriculture fertilizer loadings in the winter vs. summer) are used to project seasonal variations throughout the simulation.

Exhibit 4-11 presents the comparison of simulated and observed data for nitrogen loadings by source and season. The results are consistent with those presented above, primarily due to the use of exogenous inputs to introduce the seasonality in the model. In fact, the totals by loadings source category reflect the values presented in Exhibit 4-9 and 4-10, with the exception of only a small difference due to the use of seasonal rather than annual time steps.

Nitrogen loading is the main endogenous driver used to estimate nitrogen concentration in each of the 14 bay boxes represented in the model. On the other hand, nitrogen concentration is influenced by several other factors, which are not captured by the model (e.g. wind, currents and temperature). The model adds a "noise" factor in order to reproduce the variation seen in the historical data and presumably caused by these other factors. Exhibit 4-12 shows nitrogen concentration in Box 4 with (top graph) and without (bottom graph) the addition of a noise factor. These simulations are compared with historical data for the period 2006-2010 (green lines).

EXHIBIT 4-12. BASELINE SIMULATION AND HISTORICAL DATA FOR NITROGEN CONCENTRATION, BOX 4 (MG/L) WITH NOISE (TOP GRAPH) AND WITHOUT NOISE (BOTTOM GRAPH)





The simulation with no noise can be described as one showing only the contribution of nitrogen loadings to concentration in Box 4. As the exhibit shows, the model projection with no noise (blue) generates far less variability than what is observed in reality. The simulation with noise (red), on the other hand, more closely resembles the pattern seen in the historical data, at least in terms of the magnitude and frequency of variation. In the model, the noise in nitrogen concentration is amplified by noise in precipitation, meaning that an increase in the variation of rainfall would lead to an increase in the variation of nitrogen concentration.

Exhibit 4-13 shows that in the simulation without noise, projected bay box concentrations are within 16 percent of observed data values just under half of the time and within the 30 percent error threshold approximately three-quarters of the time. This applies to both individual years and to the average across all five years for which we have data for individual bay boxes. The model produced the poorest fit in 2009, a year with lower measured nitrogen concentrations. The addition of the nitrogen noise factor is not intended to improve the fit of 3VS simulations to historical data, and, as presented in the bottom two rows of Exhibit 4-13, the added noise marginally lowers the accuracy of the model. On the other hand, the noise factor does provide a more complete representation of the magnitude of the variability and changes in nitrogen concentration, which is needed to estimate environmental impacts of alternate policy interventions. In fact, a relatively stable nitrogen concentration, showing little sensitivity to changes in nitrogen loadings (by not accounting for other factors that impact nitrogen concentration) would lead to the underestimation of potential environmental impacts of changes in nitrogen loadings. Some of these are estimated in absolute terms (e.g. chlorophyll A), while others are estimated through composite indices (e.g. hypoxia risk).

We use estimates of local residence time (LRT) as another key factor in projecting nitrogen concentration by box. This value is responsible for the accumulation of the stock of nitrogen in each box. Exhibit 4-14 (which repeats Exhibit 2-13) shows both estimated data (based on the work of Abdelrhman (2004) and refined using a net system water balance approach)[11] and the values used in the Narragansett 3VS model. We could not use all the observed values in projecting nitrogen, due to limitations in the model in capturing many of the physical factors that affect nitrogen concentration in each bay box. This becomes evident when simulating the model, as the use of endogenously calibrated nitrogen loadings, when combined with assumptions of denitrification and of nitrogen flows across boxes leads to results considerably different from the historical data (e.g. Box 12, presented in more detail in Exhibit 4-18).

[11] For more details see Section 2-7.

EXHIBIT 4-13. COMPARISON OF BASELINE SIMULATION (WITHOUT NITROGEN CONCENTRATION NOISE FACTOR) AND DATA, NITROGEN CONCENTRATION BY BOX (MG/L)

BAY BOX	2006		2007		2008		2009		2010		2006-2010	
	AVG CONC	% VS DATA	AVG CONC	% VS DATA	AVG CONC	% VS DATA	AVG CONC	% VS DATA	AVG CONC	% VS DATA	AVG CONC	% VS DATA
N conc box 1	0.92	19%	0.87	29%	0.84	30%	0.88	44%	0.89	68%	0.88	36%
N conc box 2	0.58	6%	0.54	22%	0.52	-7%	0.56	16%	0.57	9%	0.55	8%
N conc Box 3	0.58	20%	0.54	25%	0.53	27%	0.55	47%	0.56	17%	0.55	26%
N conc box 4	0.32	-4%	0.30	-5%	0.31	8%	0.31	33%	0.31	-6%	0.31	3%
N conc box 5	0.33	19%	0.31	21%	0.32	36%	0.32	59%	0.32	15%	0.32	28%
N conc box GB[1]	0.32	-19%	0.29	-28%	0.32	-27%	0.30	-8%	0.30	-2%	0.31	-18%
N conc box 8	0.25	1%	0.24	-6%	0.26	7%	0.24	23%	0.24	25%	0.24	9%
N conc box 9	0.34	11%	0.32	15%	0.34	46%	0.33	68%	0.32	3%	0.33	25%
N conc box 10	0.26	-25%	0.23	-42%	0.24	-24%	0.24	9%	0.25	-11%	0.24	-22%
N conc box 11	0.21	-16%	0.19	-14%	0.21	-5%	0.2	55%	0.19	-20%	0.20	-6%
N conc box 12	0.25	8%	0.24	4%	0.26	38%	0.24	40%	0.24	1%	0.25	16%
N conc box 13	0.19	-16%	0.17	6%	0.19	-9%	0.18	49%	0.18	-19%	0.18	-3%
N conc box 14	0.19	-11%	0.18	-6%	0.19	18%	0.18	66%	0.18	-4%	0.18	7%
Avg % vs data	13%		17%		22%		40%		15%		16%	
Avg % vs data with noise	19%		20%		32%		54%		16%		21%	

Notes:
1. For Greenwich Bay, we had monthly average data for the cumulative period from 2006 to 2010. These data were applied to individual years for purposes of calibration.

In developing the final LRT model inputs, we weighed the tradeoffs between maximizing the fit with historical data and the use of more coherent and defendable LRT values. With some exceptions (e.g., boxes 2, 10, 11, 12, and 13), we opted to sacrifice accuracy in the projections to use more coherent and defendable LRT values. As a result, the model tends to overestimate nitrogen concentration (except for Box 10 and Greenwich Bay where nitrogen concentration tends to be underestimated). More specifically, as shown in Exhibit 4-12 and by the results of the simulations, the model effectively captures increases in nitrogen concentration due to precipitation and nitrogen loadings, but it does not capture declines in nitrogen concentration due to precipitation as well. The addition of noise to nitrogen concentration does not change the results significantly, although it does help in that it amplifies the reductions in nitrogen loadings.

EXHIBIT 4-14. BAY BOX RESIDENCE TIMES

BOX NUMBER	BOX NAME	LOCAL RESIDENCE TIME OBSERVATIONS* (HOURS)	LOCAL RESIDENCE TIME MODEL INPUT (HOURS)
1	Providence River Estuary, North of Fields Point	67.2	67.2
2	Providence River Estuary, South of Fields Point	85.0	45.0
3	Upper Bay North (Barrington)	109.8	109.8
4	Upper Bay West (Warwick Neck)	132.0	132.0
5	Upper Bay East (Colt State Park)	135.0	135.0
6 & 7	Greenwich Bay	196.8	196.8
8	Upper West Passage (South of Greenwich Bay)	252.0	252.0
9	Upper East Passage (Bristol)	130.0	170.0
10	Mount Hope Bay	132.0	250.0
11	Middle West Passage (Quonset Point)	219.6	350.0
12	Middle East Passage (South of Prudence Island)	262.8	170.0
13	Lower West Passage (Dutch Island)	128.4	200.0
14	Lower East Passage (Newport)	219.4	219.4

* Source: Adelrhman 2004.

SENSITIVITY ANALYSIS

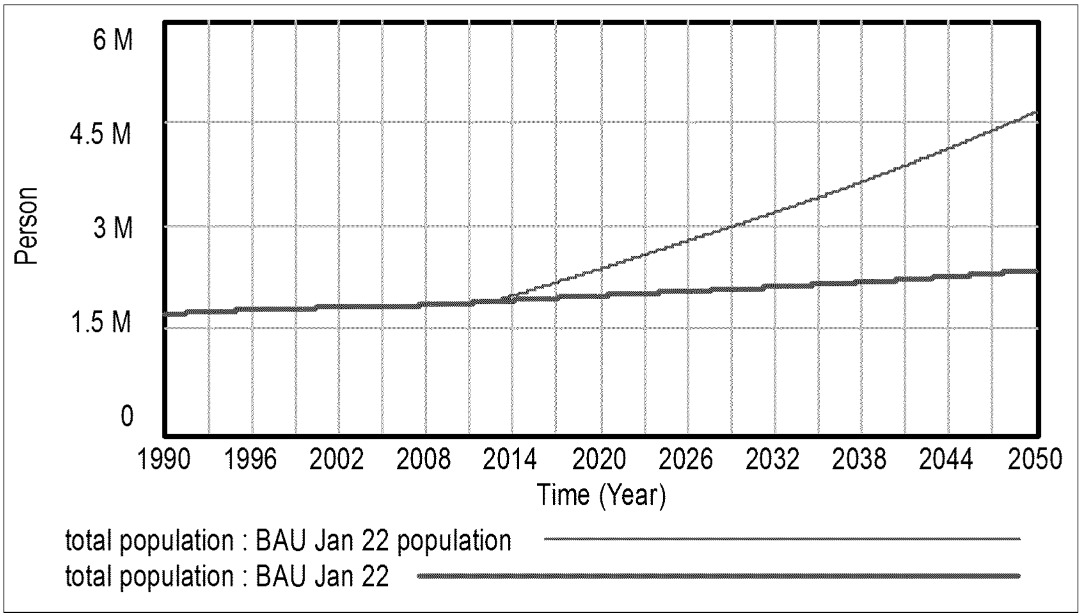
Three different types of sensitivity analysis have been carried out to test the Narragansett 3VS model: numerical, behavior mode, and policy sensitivity.

Numerical Sensitivity

Numerical sensitivity exists when a change in assumptions affects the numerical values of the results. All models exhibit numerical sensitivity. We conducted several tests of the model's numerical sensitivity; the example presented below involves examining the impacts of changing the projected value of total population. In this test, two hundred scenarios were simulated, with population ranging from the values of the baseline case, to up to a doubling of this value by 2050.

As indicated in Exhibit 4-15, an increase in total population (shown as the blue line in the top graph) is accompanied by an increase in WWTF nitrogen loadings (shown as the blue line in the bottom graph), which are driven by population. The graph on the bottom shows sensitivity for both summer and winter loadings for WWTF. Increased population also increases total loadings from ISDS, though this is not shown in the graph.

EXHIBIT 4-15. SENSITIVITY ANALYSIS FOR TOTAL POPULATION: POPULATION (TOP GRAPH) AND TOTAL ANNUAL NITROGEN LOADINGS FROM WWTFS (BOTTOM GRAPH)



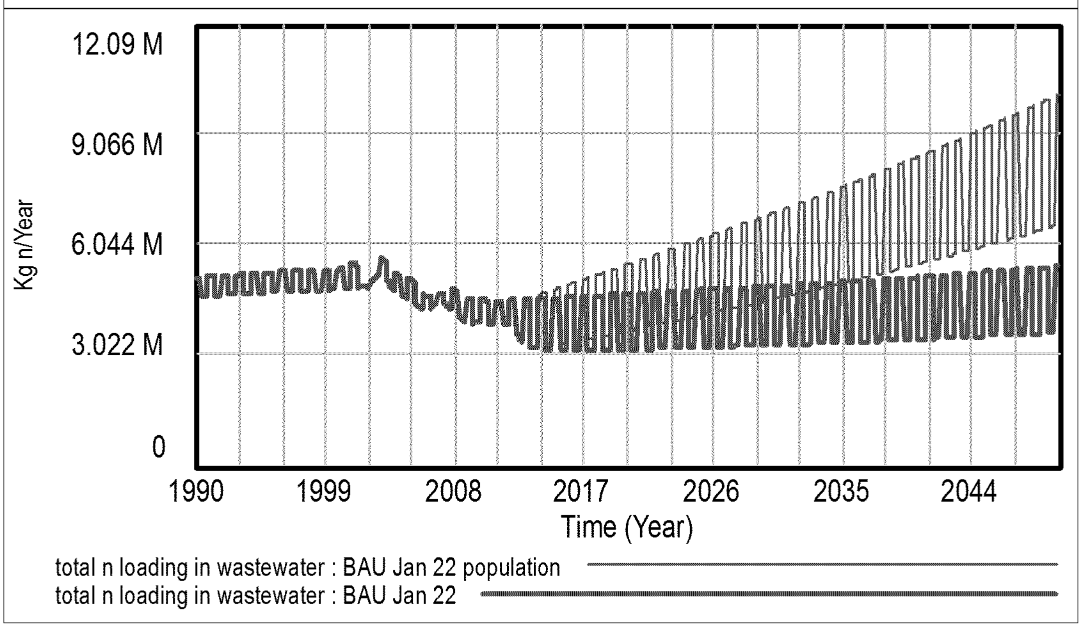


Exhibit 4-16 indicates that an increase in population and the corresponding higher nitrogen loadings from wastewater are also reflected in total nitrogen loadings and nitrogen concentration. More specifically, total loadings approximately double by 2050 as a result of doubling population. This is due to the fact that WWTF nitrogen loadings represent close to 65 percent of total loadings, but also fertilizer and ISDS are partly driven by population. The concentration for Box 1 (shown as an example) also follows a similar pattern. Note that the graphs in Exhibit 4-16 show the range of outputs generated from the 200-simulation sensitivity test. Starting in 2013, where the scenarios begin varying the population input values, the blue lines represent the 95-percent confidence interval for possible outputs given the range of population inputs, the green lines represent the 75-percent confidence interval, and the yellow area represents the interquartile range.

EXHIBIT 4-16. SENSITIVITY ANALYSIS FOR TOTAL POPULATION: CHANGE IN TOTAL ANNUAL NITROGEN LOADINGS (KG N/YEAR, TOP GRAPH) AND NITROGEN CONCENTRATION IN BOX 1 (MG/L, BOTTOM GRAPH) AS POPULATION DOUBLES

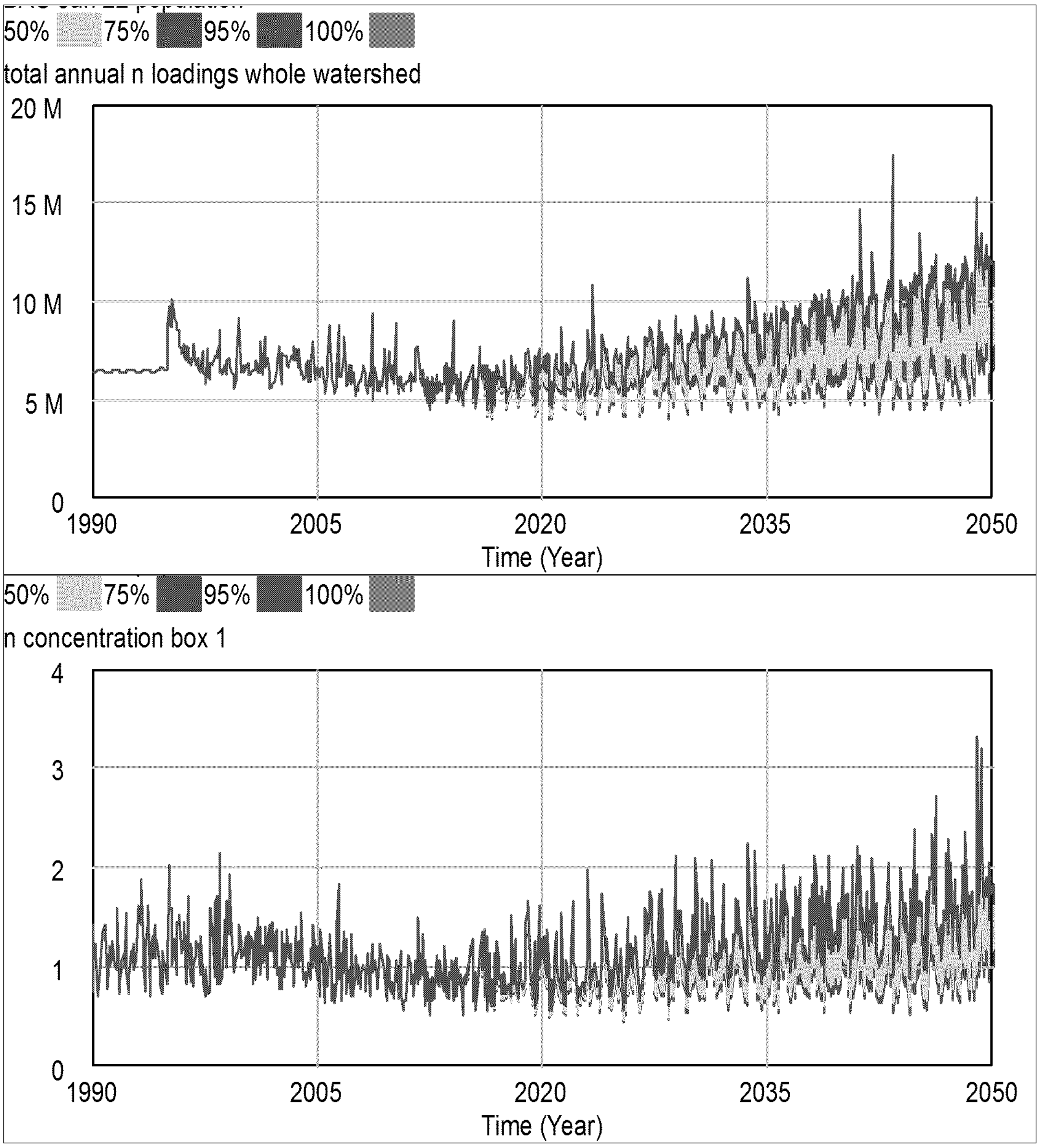


Exhibit 4-17 shows the sensitivity of selected key variables in the model to changes in total population. The change simulated is a doubling of population by 2050 (assuming a linear increase starting in 2013). This corresponds to the upper boundary of the sensitivity simulations shown above and results in an average increase in population of 50.7 percent compared to baseline values during 2013-2050. Nitrogen loadings and concentration – which are more directly impacted by population growth – show a similar degree of sensitivity (approximately 39 percent). Among the factors that are indirectly affected by population, chlorophyll A shows the highest sensitivity (approximately 95 percent) and property tax revenue the lowest (in the range of two percent or less). As the exhibit shows, for all variables the sensitivity is higher at the end of the projection when the magnitude of the change in population is highest.

EXHIBIT 4-17. SENSITIVITY ANALYSIS FOR TOTAL POPULATION, COMPARISON OF THE IMPACT OF POPULATION GROWTH ON SELECTED VARIABLES.

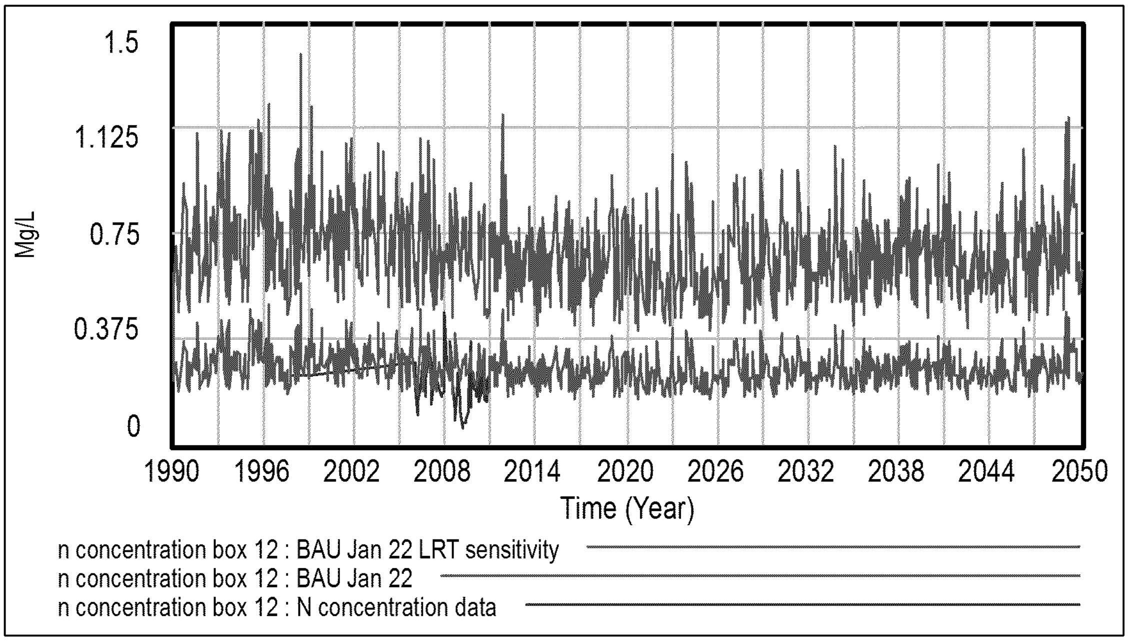
	AVERAGE 2013-2050 VALUES, BASELINE VS. HIGH POPULATION[1]	AVERAGE 2048-2050 VALUES, BASELINE VS. HIGH POPULATION[1]
Total population	50.7%	94.1%
Total annual N loadings whole watershed	38.8%	75.4%
N concentration Box 1	40.0%	80.3%
Annual Chlorophyll A concentration Box 1	94.8%	214.1%
Hypoxia risk Box 4	9.4%	13.2%
Eel grass potential Box 4	-9.6%	-36.0%
Summer only monthly beach visits Box 4	-9.1%	-29.0%
Annual property tax revenue whole watershed	-0.8%	-1.8%
Annual finfish landings revenue upper bay	-19.0%	-42.1%

Notes:
1. Average values are presented (2013 - 2050 and 2048 - 2050) to ensure that values in the table are representative and not driven by random noise factors added to precipitation and N concentration.

Behavior Mode Sensitivity

Behavior mode sensitivity exists when a change in assumptions changes the patterns of behavior generated by the model. This can be seen with the increase in population presented above, which leads to growing nitrogen loadings, as well as growing nitrogen concentration in the bay and the worsening of environmental impacts. Precipitation, also a very important driver of nitrogen loadings, has similar impacts. An increase in precipitation trends, or in oscillations (represented in the model as increased short-term variability), will impact the projections of nitrogen loadings and concentration. As an additional example, the model results appear to be sensitive to changes in LRT. If we were to use the observed value from the literature for Box 12, the projected environmental impacts of a particular change in nitrogen loadings would be much higher than observed, changing the pattern of behavior generated by the model (from potentially improving over time, to considerably worsening). Exhibit 4-18 shows the model's estimated nitrogen concentration in Box 12 when using the LRT value based on observed data of 262.8 hours (blue line) and when using the calibrated input of 170 hours (red line). It is clear that the use of observed residence time data generates a higher buildup of nitrogen in Box 12, an order of magnitude above the historical data for the period 2006 – 2010 (green line).

EXHIBIT 4-18. NITROGEN CONCENTRATION IN BOX 12, USING OBSERVED AND CALIBRATED LRT



Policy Sensitivity

Policy sensitivity exists when a change in assumptions changes the impacts or desirability of a proposed policy. An example of this would be a future increase in precipitation. If the goal of a policy were to lower nitrogen concentration in the bay below current levels, a 20 percent reduction in nitrogen loadings relative to the baseline would be needed by 2050. On the other hand, if rainfall were to increase by 30 percent above the baseline during the same period, nitrogen concentration would increase (despite the policy-induced reduction in nitrogen loadings), making the policy intervention less effective, preventing it from meeting the target. An increase in other variables that drive nitrogen loadings (e.g., impervious area) would have a similar effect.

The example above presents the case in which the desirability of a proposed policy may change under different assumptions. A reversal of the impacts of policy interventions could also emerge from feedback loops that would reinforce or balance the impact of interventions, but in its current form the model does not include strong feedback loops that would have meaningful impacts across sectors (e.g., the feedback between economic development policies and environmental damage, which would in turn influence the economy, are not fully built into the model).

Both univariate and multivariate sensitivity analyses were also performed, as indicated above, to test the impacts of changing assumptions for several variables simultaneously. Using the same example of a change in precipitation, Exhibit 4-19 shows that a doubling in rainfall by 2050 (top graph) results in an average increase in loadings of 18 percent (bottom graph). Exhibit 4-20 illustrates what might happen if WWTF loadings were reduced by 60 percent as a response to increased pollution levels caused by higher precipitation (blue line), illustrating changes to WWTF loadings over the whole period (top graph) as well as in the period from 2040 to 2050. While a 60 percent reduction in WWTF summer loadings would lower loadings to the baseline amount, it would not reduce the vulnerability of the system (i.e.

environmental impacts) to the baseline level in cases of high rainfall. This is due to the fact that rainfall affects several nitrogen loadings categories that are not affected by WWTF upgrades (e.g., atmospheric deposition and runoff), as well as affecting nitrogen concentrations directly. As a result, Exhibit 4-21 shows that environmental impacts including nitrogen concentration (top graph), chlorophyll a (middle graph), and water clarity (bottom graph) are generally mitigated under this scenario, but not necessarily under high precipitation events (as evidenced by the fact that the blue line is occasionally as high as the red and green lines during high-precipitation spikes).

EXHIBIT 4-19. SENSITIVITY ANALYSIS FOR HIGH PRECIPITATION: PRECIPITATION (TOP GRAPH) AND TOTAL NITROGEN LOADINGS (BOTTOM GRAPH)

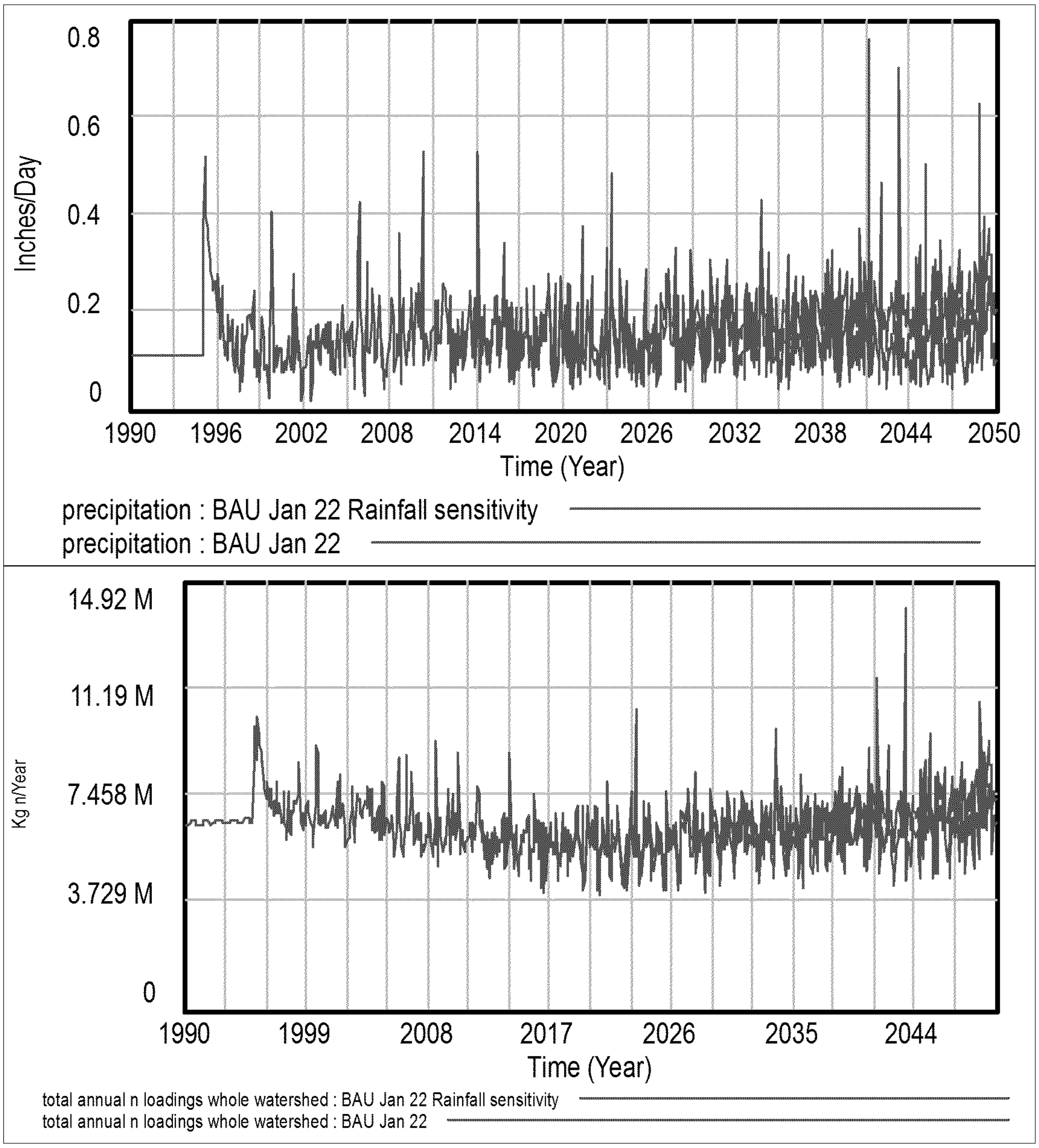
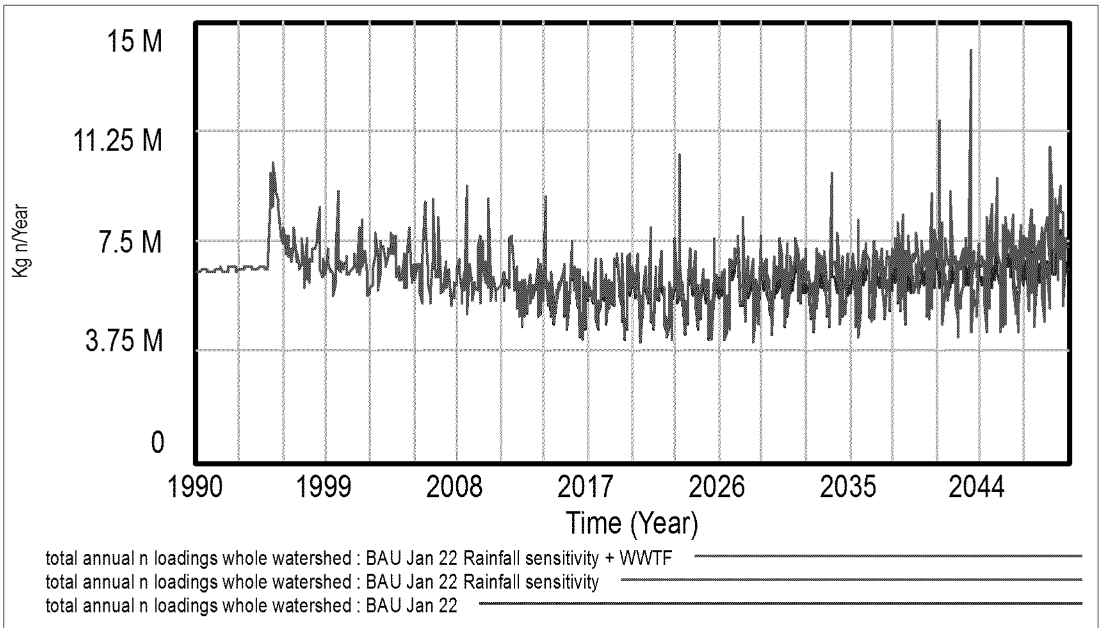


EXHIBIT 4-20. SENSITIVITY ANALYSIS FOR HIGH PRECIPITATION AND 60 PERCENT REDUCTION IN WWTF NITROGEN: TOTAL NITROGEN LOADINGS WHOLE PERIOD (TOP GRAPH) AND 2040-2050 (BOTTOM GRAPH)



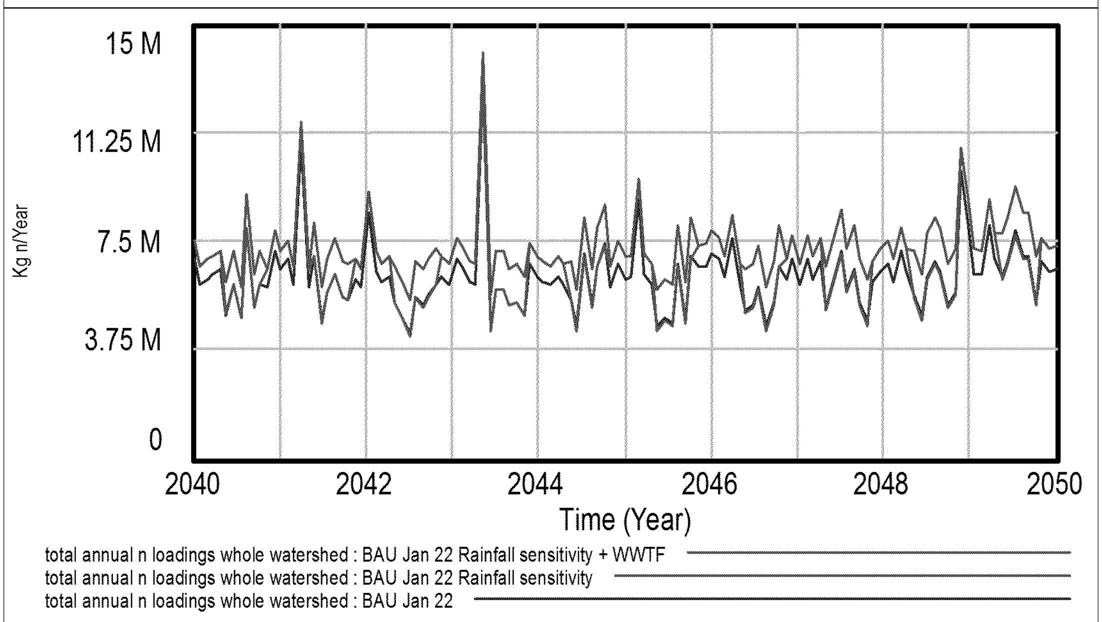
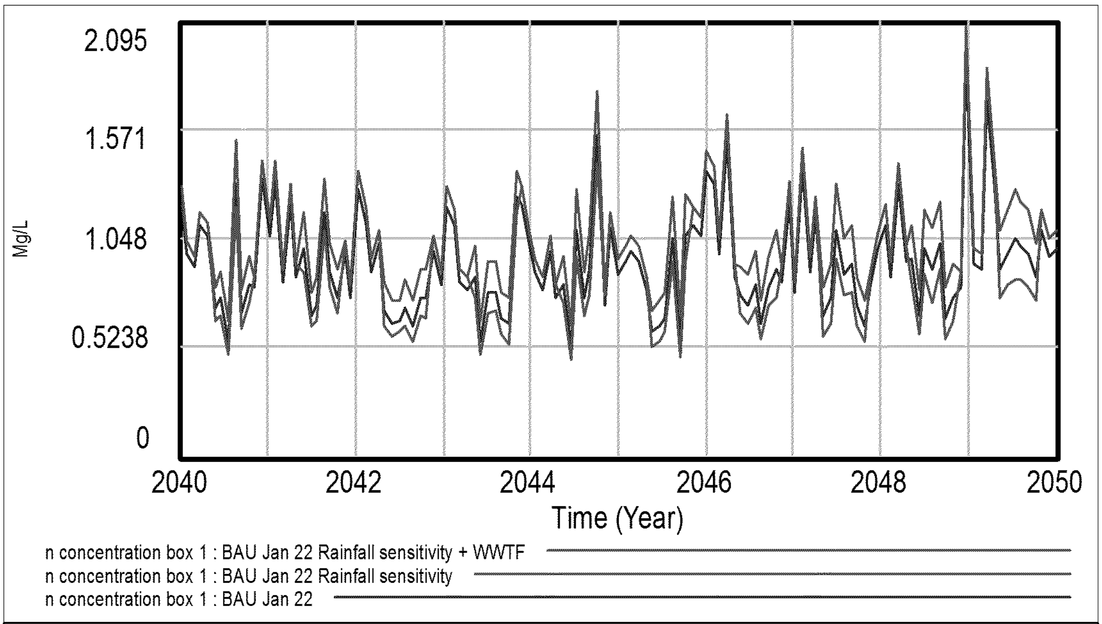
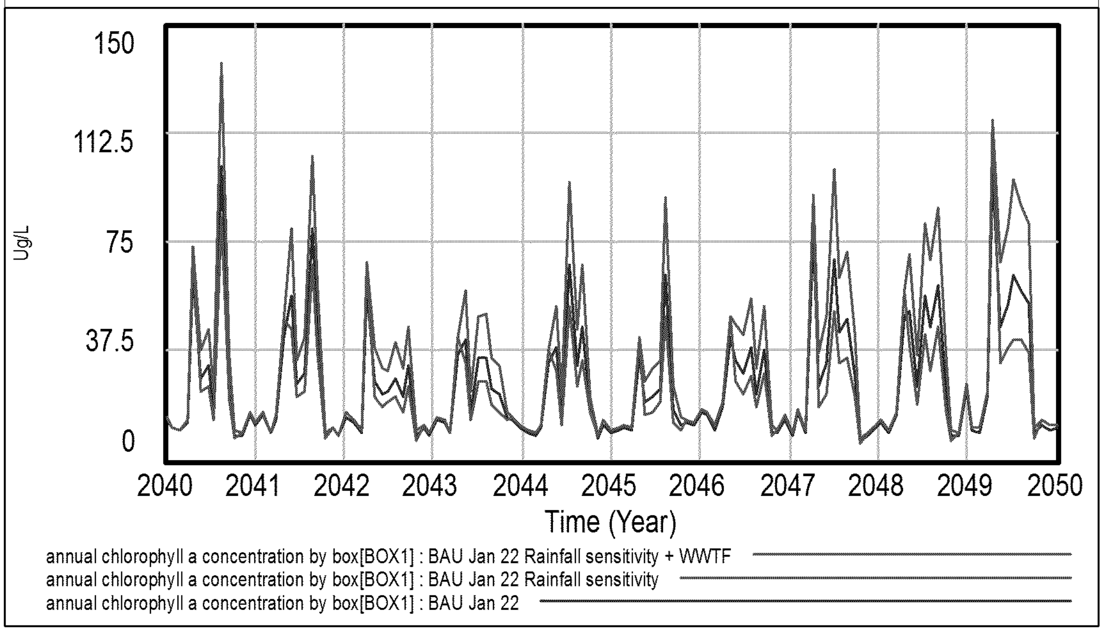
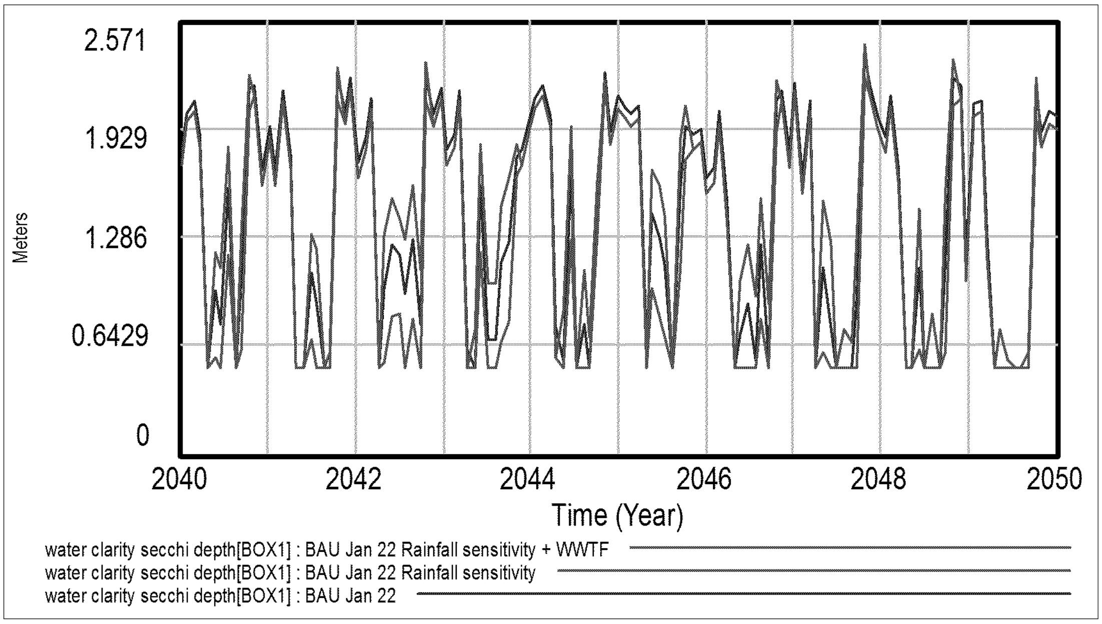


EXHIBIT 4-21. SENSITIVITY ANALYSIS FOR HIGH PRECIPITATION AND 60 PERCENT REDUCTION IN WWTF NITROGEN. ENVIRONMENTAL IMPACTS IN BOX 1, 2040 - 2050: NITROGEN CONCENTRATION (TOP GRAPH), CHLOROPHYLL A (MIDDLE GRAPH) AND WATER CLARITY (BOTTOM GRAPH).







4-3. MODEL CORROBORATION (VALIDATION AND SIMULATION)

The ultimate objective of system dynamics model validation is to establish the validity of the structure of the model. Accuracy of the model's reproduction of real behavior is also evaluated, but this is meaningful only if we first have sufficient confidence in the structure of the model. Thus, we test the validity of the model structure prior to testing its behavioral accuracy.

DIRECT STRUCTURE TESTS

Direct structure tests assess the validity of the model structure by direct comparison with knowledge about the structure of the real system. This involves assessing each relationship within the model individually and comparing it to available knowledge about the real system. Several direct structure tests have been illustrated above. These include structure and parameter confirmation tests, which primarily include the testing and use of equations and data (or assumptions) obtained from other sources (as shown in Exhibits 4-9 and 4-10), and behavior sensitivity tests (as shown in Exhibit 4-18). Additional tests described below include structure confirmation tests, extreme condition tests, and unit consistency tests.

Structure Confirmation Tests

Structure confirmation tests have been performed for all the key variables of the model by testing them first against existing literature and second against available data (both historical information and outputs of other models). The comparison with available historical data in the model development phase, when exogenous assumptions were replaced with endogenous formulations, allowed us to carry out parameter confirmation tests by checking the coherence of each parameter used (regardless of the source) in the integrated structure of Narragansett 3VS model. One example is the use of LRT values obtained from literature, which were tested against initial simulations that made use of exogenous nitrogen loadings, a denitrification parameter and nitrogen flows across boxes. With all the other inputs already tested and validated, if LRT values from the literature did not allow the model to match the historical data on nitrogen concentration in the period 2006 – 2010, we decided whether to adjust the input parameters for residence time to better fit the historical data.

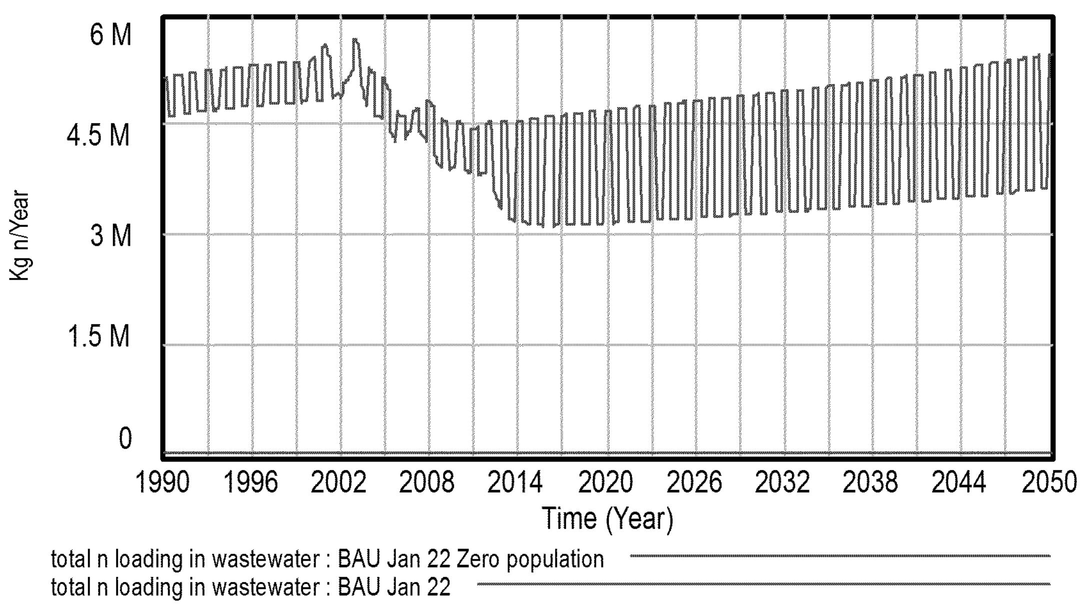
Extreme-Condition Tests

The direct extreme-condition testing is a very important step in the validation of the Narragansett 3VS model. Testing the model for extreme conditions involves evaluating the validity of model equations under extreme (not necessarily plausible) conditions, by assessing the coherence of the resulting values against the knowledge or anticipation of what would happen under a similar condition in real life.

As an example, in order to test the validity of the structure of the model, especially in relation to nitrogen loadings, we lowered population to zero from the beginning of the simulation. Under such conditions, we expect that nitrogen loadings would decline, especially from wastewater, but also from fertilizer. With no population, the model confirms expectations and shows that nitrogen loadings from WWTF and ISDS, as well as residential and agriculture fertilizer would decline to zero. As shown in Exhibit 4-22, nitrogen loadings from WWTFs decline to zero (top graph), but total loadings to the bay do not decline to zero (bottom graph), as loadings would still originate from atmospheric deposition as well as animals. Concerning the latter, it is assumed that population affects livestock production and slaughtering, not the growth of the animal stock. For this reason, loadings from animals do not change in the "no population" scenario.

The reduction in loadings under this scenario leads to lower nitrogen concentration in the bay. This reduction is more marked in the upper bay than in the southern part of Narragansett Bay, near the ocean, due to the more significant human presence (and resulting nitrogen flows, e.g., from WWTFs) in the upper bay. Exhibit 4-23 shows nitrogen concentration in Box 1 (top graph) and Box 14 (bottom graph). Since the projected level of nitrogen concentration in the no-population scenario may be unrealistic, especially in Box 14, it should be noted that the model does not capture nitrogen flows from the ocean. Were it captured, this flow would likely balance the reduction in loadings in the no-population scenario to reach an equilibrium closer to the baseline for this box.

EXHIBIT 4-22. ANNUAL NITROGEN LOADINGS IN THE POPULATION EXTREME CASE: WASTEWATER LOADINGS (TOP GRAPH) AND TOTAL LOADINGS (BOTTOM GRAPH);



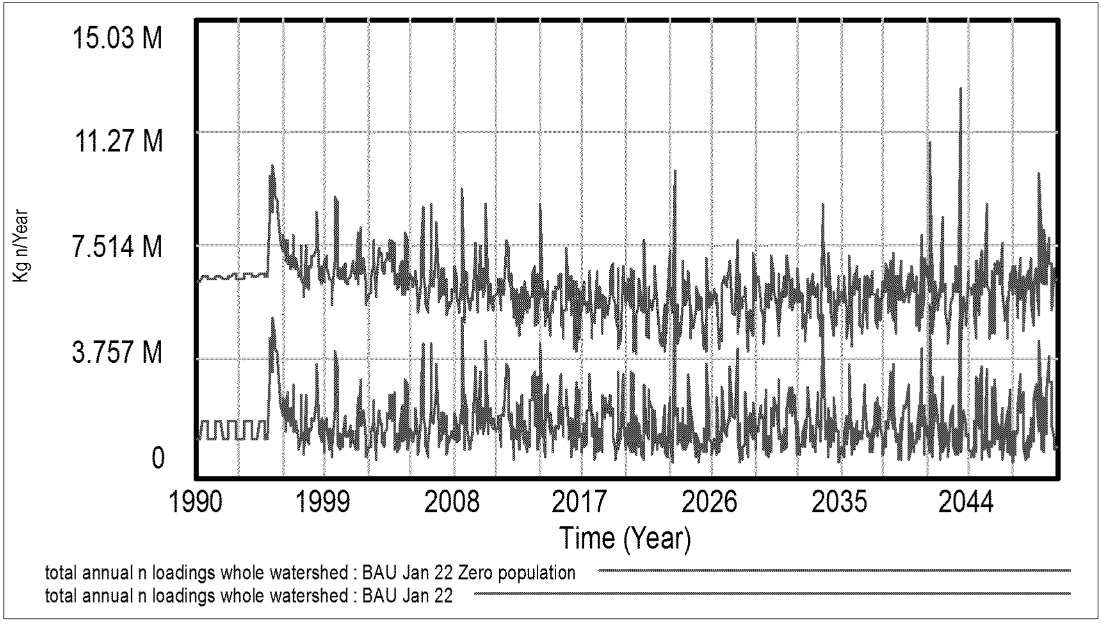
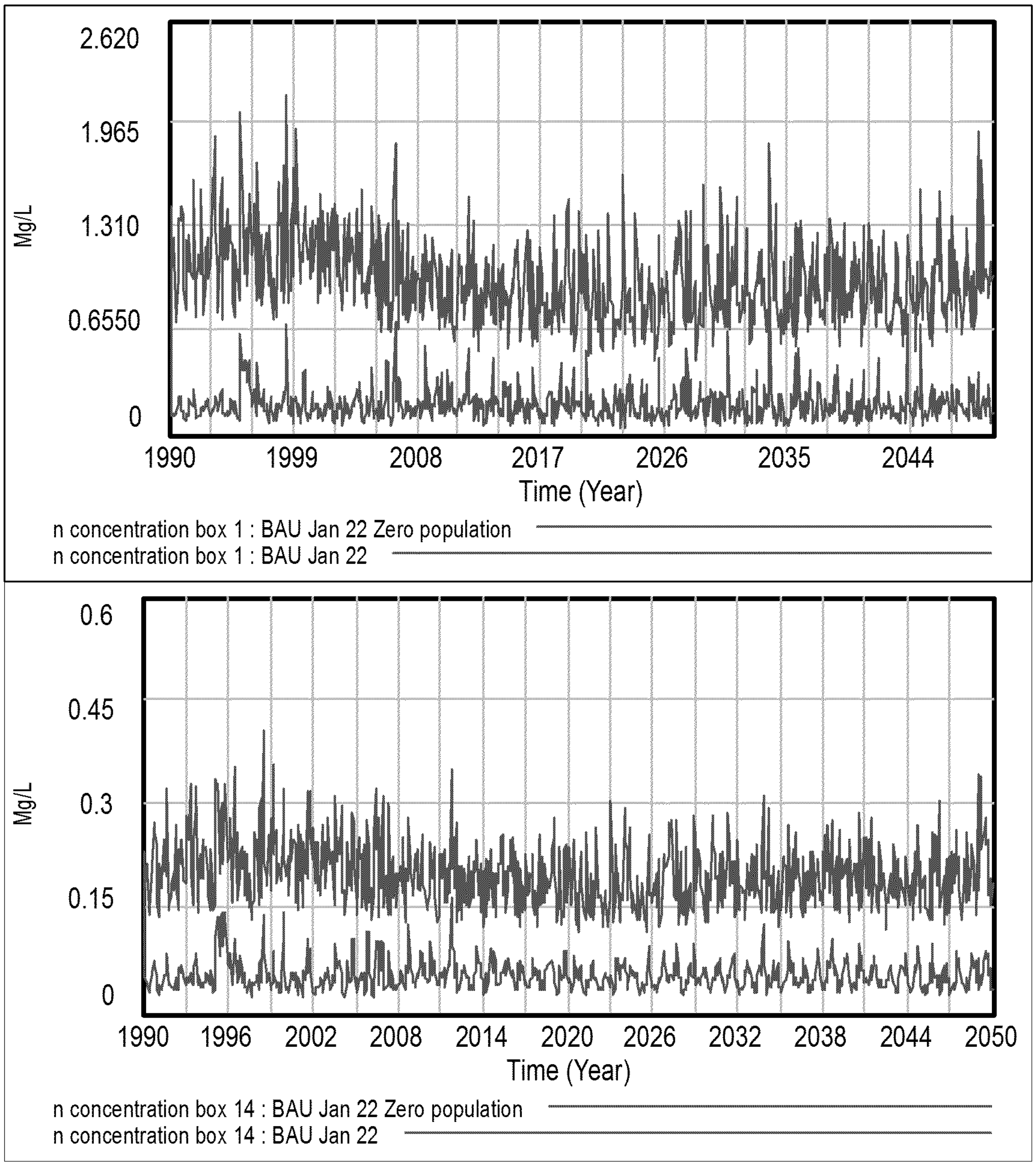


EXHIBIT 4-23. NITROGEN CONCENTRATION IN THE POPULATION EXTREME CASE: BOX 1 (TOP GRAPH) AND BOX 14 (BOTTOM GRAPH)



Gradient Testing

As part of our efforts to conduct structure tests particularly relevant to the Narragansett 3VS model, and the bay box disaggregation incorporated into it, we present model outputs that describe the north-south and east-west gradients of three water parameters across the bay. Exhibit 4-24 shows the results of two simulations and compares them with the baseline scenario. Specifically, a 50 percent reduction in nitrogen loadings was assumed to take place beginning in 2015 in Box 1 (top table) and in Box 10 (second bottom table). The nitrogen loadings reduction in Box 1 (Providence River Estuary, North of Fields Point), which is situated in the north of the bay, is used to evaluate the north-south gradients. The nitrogen loadings reduction in Box 10 (Mount Hope Bay), which is situated in the eastern side of the bay, is used to evaluate the east-west gradients. Results are presented for nitrogen concentration, Chlorophyll A and water clarity (as measured by Secchi depth). For reference, Exhibit 4-25 (which reproduces Exhibit 2-12), presents a map of Narragansett Bay, showing the location of the 14 bay boxes.

The simulation for Box 1 indicates that a reduction in nitrogen loadings that originates in the northern end of the bay is mitigated when reaching the southern part of the bay. This is due to different gradients among boxes, and also to the denitrification taking place in each box, which is fixed at a 30 percent annual share of the nitrogen stock of each box. Reductions also can be observed in Greenwich Bay (Boxes 6 and 7), as the model accounts for bidirectional nitrogen flows: from Box 4 to Greenwich Bay and from Greenwich Bay to Box 8. In addition, Box 10 is not affected, as the model does not simulate northward flow of nitrogen from Box 9 to Box 10.

The simulation for Box 10 shows that only a few boxes are affected by a reduction in nitrogen loadings in the eastern part of the bay. In fact, a nitrogen loadings reduction in Box 10 affects only Boxes 9, 12 and 14. The reduction in nitrogen loadings is mitigated in this case as well, and it does take into account that Box 9 is affected both by Box 10 (with reduced loadings) and Box 5 (with baseline loadings). This is shown by the 19 percent reduction in nitrogen concentration simulated for Box 9, a result of a 50 percent reduction in Box 10 and no reduction in Box 5.

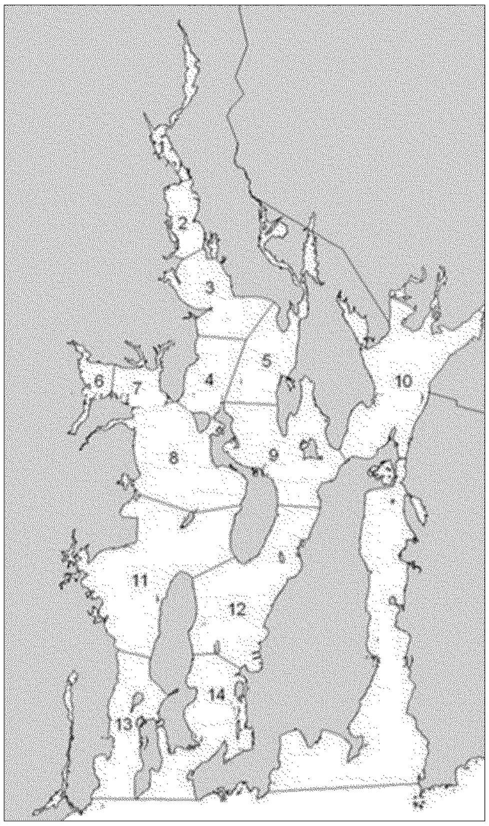
EXHIBIT 4-24. COMPARISON OF BASELINE SIMULATION AND NITROGEN REDUCTION SCENARIOS FOR BOX 1 (TOP TABLE) AND BOX 10 (BOTTOM TABLE): NITROGEN CONCENTRATION, CHLOROPHYLL A, AND SECCHI DEPTH

	Box 1 Scenario								
	N concentration (mg/L)			Chlorophyll A (µg/L)			Secchi depth (meters)		
	Box 1 Reduction (50%)	Baseline	Ratio	Box 1 Reduction (50%)	Baseline	Ratio	Box 1 Reduction (50%)	Baseline	Ratio
Box 1	0.45	0.90	50%	7.07	26.18	27%	2.25	1.48	153%
Box 2	0.33	0.56	59%	3.88	9.97	39%	2.50	2.05	122%
Box 3	0.35	0.59	58%	4.38	11.93	37%	2.46	1.94	127%
Box 4	0.19	0.32	60%	1.55	3.84	40%	2.69	2.50	108%
Box 5	0.21	0.33	62%	1.78	4.10	43%	2.67	2.48	108%
GB	0.21	0.32	65%	1.75	3.79	46%	2.68	2.50	107%
Box 8	0.16	0.25	64%	1.16	2.54	46%	2.73	2.61	105%
Box 9	0.27	0.34	78%	2.83	4.43	64%	2.58	2.45	105%
Box 10	0.26	0.26	100%	2.79	2.79	100%	2.59	2.59	100%
Box 11	0.14	0.21	67%	0.88	1.79	49%	2.75	2.67	103%
Box 12	0.20	0.26	78%	1.68	2.60	65%	2.68	2.60	103%
Box 13	0.13	0.19	68%	0.80	1.55	51%	2.76	2.69	102%
Box 14	0.15	0.19	80%	1.04	1.55	67%	2.74	2.69	102%

	Box 10 Scenario								
	N concentration (mg/L)			Chlorophyll A (µg/L)			Secchi depth (meters)		
	Box 10 Reduction (50%)	Baseline	Ratio	Box 10 Reduction (50%)	Baseline	Ratio	Box 10 Reduction (50%)	Baseline	Ratio
Box 1	0.90	0.90	100%	26.18	26.18	100%	1.48	1.48	100%
Box 2	0.56	0.56	100%	9.97	9.97	100%	2.05	2.05	100%
Box 3	0.59	0.59	100%	11.93	11.93	100%	1.94	1.94	100%
Box 4	0.32	0.32	100%	3.84	3.84	100%	2.50	2.50	100%
Box 5	0.33	0.33	100%	4.10	4.10	100%	2.48	2.48	100%
GB	0.32	0.32	100%	3.79	3.79	100%	2.50	2.50	100%
Box 8	0.25	0.25	100%	2.54	2.54	100%	2.61	2.61	100%
Box 9	0.28	0.34	81%	3.03	4.43	69%	2.57	2.45	105%
Box 10	0.13	0.26	50%	0.82	2.79	30%	2.76	2.59	107%
Box 11	0.21	0.21	100%	1.79	1.79	100%	2.67	2.67	100%
Box 12	0.21	0.26	82%	1.82	2.60	70%	2.67	2.60	103%
Box 13	0.19	0.19	100%	1.55	1.55	100%	2.69	2.69	100%

Box 14	0.16	0.19	83%	1.12	1.55	72%	2.73	2.69	101%

EXHIBIT 4-25. MAP OF NARRAGANSETT BAY WITH BOXES LABELED



Legend

Box 1: Providence River Estuary, North of Fields Point

Box 2: Providence River Estuary, South of Fields Point

Box 3: Upper Bay North (Barrington)

Box 4: Upper Bay West (Warwick Neck)

Box 5: Upper Bay East (Colt State Park)

Box 6: Inner Greenwich Bay

Box 7: Outer Greenwich Bay

Box 8: Upper West Passage (South of Greenwich Bay)

Box 9: Upper East Passage (Bristol)

Box 10: Mount Hope Bay

Box 11: Middle West Passage (Quonset Point)

Box 12: Middle East Passage (South of Prudence Island)

Box 13: Lower West Passage (Dutch Island)

Box 14: Lower East Passage (Newport)

Unit Consistency

Unit consistency was checked and ensured both during model development and after the completion of the Narragansett 3VS model (see Exhibit 4-26 for a list of selected indicators and their unit of measure). Further, Vensim has a specific feature, called "units check," that allows users to quickly identify errors or inconsistencies in the units used in the model. Still, for models of this type and size, it is very likely that Vensim will identify unit "errors" even when the units are correct. Below we present an example of why this may happen, but it should be also noted that such unit errors do not impact the simulations and the quality of the results generated.

- Vensim requires that every argument of an equation be represented by a variable with a unit of measure. As an example, if we use an equation such as "A = B+10," Vensim will give us a unit error because a unit for "10" is not provided. To avoid unit errors we would need to have the following equation: "A = B+C", with C=10 and the same unit specified for each of the three variables (given that we are adding B and C). This represents a challenge in the context of the Narragansett 3VS model because often we use equations obtained from the literature and do not represent each element of the equations as a separate variable, with a specific unit of measure. For example, summer Chlorophyll A is defined as follows:
    - Summer chlorophyll A concentration by box[Boxes] = max (0, 57.5 * ((N concentration by

box[Boxes]) ^ 2.09))

Although we have carefully checked the units and made sure that this equation is correct, Vensim will give us a unit error for this variable unless “0,” “57.5” and “2.09” are represented as variables with a unit of measure. Additional detail on the 22 unit errors identified by the units check tool is provided in Appendix A.

EXHIBIT 4-26. SELECTED QUANTITATIVE INDICATORS AND UNIT OF MEASURE

CATEGORY	INDICATOR	UNIT
Economic/Social	GDP (change relative to baseline)	US$
Economic/Social	Per Capita Disposable Income	US$
Economic/Social	Property Value: - Related to Water Clarity - Related to Proximity to Open Space	US$
Economic/Social	Municipal Tax Revenue (related to changes in property value)	US$
Economic/Social	Employment (related to aquaculture)	Jobs
Economic/Social	Commercial Fish Production (finfish landings: total value and change relative to baseline)	US$
Economic/Social	Energy Use (energy demand curve for different levels of nitrogen removal)	Billion BTU
Economic/Social	Beach Visits	People
Economic/Social	Tourism Production (consumer surplus from beach visits: change relative to baseline)	US$
Economic/Social	Total Direct Cost of Nitrogen Reductions: Includes costs of - Aquaculture (calculated as US$/farm), - ISDS Improvements (US$/unit upgraded) - WWTF Reductions (US$ for O&M and annualized capital cost/kg N reduced) - Subwatershed-scale LID/GI Implementation (US$/kg N reduced) - LID/GI Use Case Retrofits (US$/acre of impervious cover reduced below initial levels) - Residential and Agricultural Fertilizer reductions (US$/kg N reduced), and - Animal Waste Reductions (US$/kg N reduced).	US$
Economic/Social	Aquaculture Revenue	US$
Environmental	Monthly and Annual Nitrogen Loadings, by box (area of the bay), subwatershed area, and source type: - WWTFs - ISDSs - Residential and Agricultural Fertilizer - Animal Waste - Atmospheric Deposition (direct to the bay and via the watershed) - Surface Water Runoff from Developed Land	kg
Environmental	Nitrogen Concentration (by Box)	mg/L
Environmental	Micro Algal Blooms (chlorophyll A)	µg/L
Environmental	Ulva Growth Rate	Percent
Environmental	Hypoxia Risk (semi-qualitative)	Unitless

Environmental	Water Clarity/Secchi Depth	NTU
Environmental	Eel Grass Improvement Potential (semi-qualitative)	Unitless
Environmental	Daily Precipitation (can be adjusted to reflect expected impacts of climate change on precipitation event frequency and size)	ml

Overall, the structure tests presented above indicate that: (1) the structure produces results consistent with historical data, without leading to unrealistic perpetual exponential growth or decay; (2) exogenous parameters are validated with peer reviewed studies or historical time series; (3) the model reflects real world phenomena when it comes to extreme-condition tests; and (4) the key units (a small sample was presented in this document) are consistent.

BEHAVIOR PATTERN TESTS

The direct structure tests discussed above are designed to evaluate the validity of the model structure. Once these tests have established an adequate level of confidence in the validity of the Narragansett 3VS model's structure, we apply a third type of test designed to measure how accurately the model reproduces the major behavioral patterns exhibited by the real system. It is crucial to note that the emphasis is on pattern prediction (periods, frequencies, trends, phase lags, amplitudes, etc.) rather than point (event) prediction. Several tools are provided by Vensim to evaluate behavioral validity against historical data (as system dynamics models allow users to start the simulation in the past and validate the historical projection with actual data), such as minimum, maximum, mean, median, standard deviation. This information is available in the "Statistics" tool of Vensim, and this type of result can be estimated for every variable and simulation in the model.

In conducting this type of test, we have applied the same criteria as we described in the model parameterization (calibration) section above. In fact, several projections have been presented and evaluated in this document already. These include:

- A modification of the population and precipitation trends, analyzing the impact on nitrogen loadings (by source of loading and bay box), nitrogen concentration and environmental impacts (see Exhibits 4-15 to 4-17 and 4-19 to 4-21);
- A reduction in nitrogen loadings, bay-wide and for specific bay boxes (50 percent reduction for Box 1 and Box 10, see Exhibit 4-24); and
- Changes in assumptions, especially concerning LRT, plus an overview of the impacts of removing a noise factor added to match the variability (and magnitude) observed in nitrogen concentration in the period 2006-2010 (see Exhibits 4-12, 4-13, and 4-18).

Several indicators in the model were not tested against historical data due to limitations in data availability. If additional data were to become available – either historical data or projections from other models – we could conduct additional behavior pattern tests to validate and further calibrate the model's structure. The following list provides a sample of the type of data that would allow for such tests:

- Nitrogen loadings data, by category, covering additional historical time periods;
- Nitrogen concentration data covering additional historical time periods;
- Summer chlorophyll A concentration by bay box;
- Summer water clarity (as measured by Secchi depth) by bay box;

- Monthly beach visits by box over time;
- Annual finfish landings revenue over time; and
- Economic accounts (e.g., GDP, government revenues, expenditures, and per capita income) by state and municipality.

4-4. COMPUTATIONAL REPRODUCIBILITY

Making model computations reproducible is critical to help researchers examine and use the results of simulation exercises. Further, it greatly helps in carrying out follow-up studies, saving time in identifying and interpreting the parameters used in the initial model and in subsequent scenarios. In general, computational reproducibility can be helpful in the following ways in the context of the Narragansett 3VS project:

- It will help the technical team that has developed the Narragansett 3VS model to reproduce scenario results and check underlying assumptions incorporated in the model. This will be particularly important as the model is used over time.
- It will also support other stakeholders who wish to use the 3VS model to assess nutrient management approaches in Narragansett Bay or apply this type of model to other locations by allowing them to fully understand the data and relationships incorporated in it through documented code; and thereby avoid spending substantial periods of time trying to figure out how model results are produced.

In order to ensure computational reproducibility, we have provided EPA with the full source code of the Narragansett 3VS model, and the Agency can make it available to qualified users. Further, model users can obtain full documentation of any scenarios they simulate, the parameters used to run them, and a summary of results from Vensim. Exhibit 4-27 provides an example of the Vensim documentation for a scenario involving a 50 percent reduction in WWTF loadings, applied linearly between 2014 and 2050.

EXHIBIT 4-27. SAMPLE "RUNS COMPARE" REPORT

Comparing Baseline Nov 8 - WWFT reduction and Baseline Nov 8

*******Lookup differences between Baseline Nov 8 - WWFT reduction and Baseline Nov 8*******

#WWTF percent reduction in N loading whole watershed# - has changed in value

X	*Baseline Nov 8 - WWFT reduction*	*Baseline Nov 8*
1990	*0*	*0*
2014	*0*	*0*
2050	*0.5*	*0*

4-5. REFERENCES

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APPENDIX A. ADDITIONAL DETAIL ON UNIT ERRORS

The “units check” tool identified 22 unit errors in the model:

```
***********************************************
Error in units for the following equation:
Annual chlorophyll A concentration by box[Boxes]  =
    max ( 0,
      IF THEN ELSE ( Time
          - INTEGER ( Time )
          > ( 0.25)
          :AND: Time
            - INTEGER ( Time )
            <= ( 0.75) ,
        57.5
          * ( ( N concentration by box[Boxes] )
            ^ 2.09) ,
        10.3
          * ( N concentration by box[Boxes] )
            ^ 1.275) )
Annual chlorophyll A concentration by box  --> ug/l
Time  --> Year
N concentration by box  --> g/m3

Analysis of units error:
Units for ^ with noninteger exponent (or > 9) must be dimensionless
( N concentration by box[Boxes] )
Has Units: g/m3

***********************************************
Error in units for the following equation:
Baseline Chlorophyll A[Boxes]  =
    max ( 0,
      IF THEN ELSE ( Time
          - INTEGER ( Time )
          > ( 0.25)
          :AND: Time
            - INTEGER ( Time )
            <= ( 0.75) ,
        57.5
```

```
                * ( ( Baseline n concentration by box[Boxes] )
                    ^ 2.09) ,
            10.3
                * ( Baseline n concentration by box[Boxes] )
                    ^ 1.275) )
Baseline Chlorophyll A  --> ug/l
Time  --> Year
Baseline n concentration by box  --> g/m3

Analysis of units error:
Units for ^ with noninteger exponent (or > 9) must be dimensionless
( Baseline n concentration by box[Boxes] )
Has Units: g/m3

**********************************************
Error in units for the following equation:
Baseline chlorophyll a score[Boxes]  =
    IF THEN ELSE ( Baseline Chlorophyll A[Boxes]
            > medium HYPOXIA RISK level 0 ,
        3,
        IF THEN ELSE ( Baseline Chlorophyll A[Boxes]
                < low HYPOXIA RISK level 0 ,
            1,
            2) )
Baseline chlorophyll a score  --> dmnl
Baseline Chlorophyll A  --> ug/l
medium HYPOXIA RISK level 0  --> dmnl
low HYPOXIA RISK level 0  --> dmnl

Analysis of units error:
Units mismatch
Baseline Chlorophyll A[Boxes]
Has Units: ug/l
low HYPOXIA RISK level 0
Has Units: Dimensionless

**********************************************
ERROR:  No units specified for - Baseline concentration log n

**********************************************
ERROR:  No units specified for - Baseline log n loading per ha

**********************************************
ERROR:  No units specified for - Baseline log n loadings per km2
```

```
*********************************************
Error in units for the following equation:
Baseline non open space loadings[watershed]  =
      IF THEN ELSE ( Time
             - INTEGER ( Time )
             > ( 0.33)
             :AND: Time
                 - INTEGER ( Time )
                 <= ( 0.833) ,
         ( ( total non open area[watershed]
             * 0.409679
             + Baseline impervious area[watershed]
                 * 7.37422)
             * adjusted relative precipitation
                 ^ elasticity of surface water runoff to precipitation
                  )
             * 1.27,
         ( ( total non open area[watershed]
             * 0.409679
             + Baseline impervious area[watershed]
                 * 7.37422)
             * adjusted relative precipitation
                 ^ elasticity of surface water runoff to precipitation
                  )
             * 0.73)
         * Baseline runoff loadings adjustment[watershed]
Baseline non open space loadings  --> kg N/Year
Time  --> Year
total non open area  --> acre
Baseline impervious area  --> acre
adjusted relative precipitation  --> dmnl
elasticity of surface water runoff to precipitation  --> dmnl
Baseline runoff loadings adjustment  --> dmnl

Analysis of units error:
Right hand and left hand units do not match
Baseline non open space loadings[watershed]
Has Units: kg N/Year
IF THEN ELSE ( Time
       - INTEGER ( Time )
       > ( 0.33)
       :AND: Time
           - INTEGER ( Time )
```

```
            <= ( 0.833) ,
    ( ( total non open area[watershed]
        * 0.409679
        + Baseline impervious area[watershed]
            * 7.37422)
        * adjusted relative precipitation
            ^ elasticity of surface water runoff to precipitation )
        * 1.27,
    ( ( total non open area[watershed]
        * 0.409679
        + Baseline impervious area[watershed]
            * 7.37422)
        * adjusted relative precipitation
            ^ elasticity of surface water runoff to precipitation )
        * 0.73)
    * Baseline runoff loadings adjustment[watershed]
Has Units: acre

**********************************************

Error in units for the following equation:
Baseline summer chlorophyll a[Boxes]  =
      max ( 0,
          57.5
              * ( ( Baseline n concentration by box[Boxes] )
                  ^ 2.09) )
Baseline summer chlorophyll a  --> ug/l
Baseline n concentration by box  --> g/m3

Analysis of units error:
Units for ^ with noninteger exponent (or > 9) must be dimensionless
( Baseline n concentration by box[Boxes] )
Has Units: g/m3

**********************************************

Error in units for the following equation:
Baseline summer water turbidity secchi depth[Boxes]  =
      IF THEN ELSE ( Baseline summer chlorophyll a[Boxes]
              > 39,
          0.5,
          2.83
              - 0.09
                  * ( Baseline summer chlorophyll a[Boxes] )
              + 0.000776
```

* (Baseline summer chlorophyll a[Boxes])
^ 2)
Baseline summer water turbidity secchi depth --> meters
Baseline summer chlorophyll a --> ug/l

Analysis of units error:
Units mismatch
2.83
- 0.09
* (Baseline summer chlorophyll a[Boxes])
Has Units: ug/l
0.000776
* (Baseline summer chlorophyll a[Boxes])
^ 2
Has Units: ug*ug/(l*l)

****
Error in units for the following equation:
Baseline water turbidity secchi depth[Boxes] =
IF THEN ELSE (Baseline Chlorophyll A[Boxes]
> 39,
0.5,
2.83
- 0.09
* (Baseline Chlorophyll A[Boxes])
+ 0.000776
* (Baseline Chlorophyll A[Boxes])
^ 2)
Baseline water turbidity secchi depth --> meters
Baseline Chlorophyll A --> ug/l

Analysis of units error:
Units mismatch
2.83
- 0.09
* (Baseline Chlorophyll A[Boxes])
Has Units: ug/l
0.000776
* (Baseline Chlorophyll A[Boxes])
^ 2
Has Units: ug*ug/(l*l)

****
Error in units for the following equation:

```
chlorophyll a score[Boxes] =
    IF THEN ELSE ( Annual chlorophyll A concentration by box[Boxes
      ]
        > medium HYPOXIA RISK level ,
      3,
      IF THEN ELSE ( Annual chlorophyll A concentration by box[
        Boxes]
          < low HYPOXIA RISK level ,
        1,
        2) )
chlorophyll a score --> dmnl
Annual chlorophyll A concentration by box --> ug/l
medium HYPOXIA RISK level --> dmnl
low HYPOXIA RISK level --> dmnl

Analysis of units error:
Units mismatch
Annual chlorophyll A concentration by box[Boxes]
Has Units: ug/l
low HYPOXIA RISK level
Has Units: Dimensionless

**********************************************
ERROR: No units specified for - concentration log n

**********************************************
Error in units for the following equation:
log n loading per ha[Boxes] =
    Ln ( Total annual N loadings by box[Boxes]
        / ( TOTAL BASIN AREA[Boxes] ) )
log n loading per ha --> dmnl
Total annual N loadings by box --> kg N/Year
TOTAL BASIN AREA --> ha

Analysis of units error:
Argument 1 of function Ln must be dimensionless
Total annual N loadings by box[Boxes]
  / ( TOTAL BASIN AREA[Boxes] )
Has Units: kg N/(Year*ha)

**********************************************
ERROR: No units specified for - log n loadings per km2

**********************************************
```

```
Error in units for the following equation:
N concentration noise  =
    IF THEN ELSE ( n concentration noise switch
         = 1,
      ( precipitation noise
         * 4)
         + 1,
      1)
N concentration noise  --> dmnl
n concentration noise switch  --> dmnl
precipitation noise  --> inches/day

Analysis of units error:
Right hand and left hand units do not match
N concentration noise
Has Units: Dimensionless
IF THEN ELSE ( n concentration noise switch
     = 1,
  ( precipitation noise
     * 4)
     + 1,
  1)
Has Units: inches/day

**********************************************
Error in units for the following equation:
non open space loadings[watershed]  =
    IF THEN ELSE ( Time
         - INTEGER ( Time )
         > ( 0.33)
         :AND: Time
            - INTEGER ( Time )
            <= ( 0.833) ,
      ( ( total non open area[watershed]
         * 0.409679
         + impervious area[watershed]
            * 7.37422)
         * adjusted relative precipitation
            ^ elasticity of surface water runoff to precipitation
            )
         * 1.27,
      ( ( total non open area[watershed]
         * 0.409679
         + impervious area[watershed]
```

```
                * 7.37422)
            * adjusted relative precipitation
                ^ elasticity of surface water runoff to precipitation
                )
            * 0.73)
        * runoff loadings adjustment[watershed]
non open space loadings  --> kg N/Year
Time  --> Year
total non open area  --> acre
impervious area  --> acre
adjusted relative precipitation  --> dmnl
elasticity of surface water runoff to precipitation  --> dmnl
runoff loadings adjustment  --> dmnl

Analysis of units error:
Right hand and left hand units do not match
non open space loadings[watershed]
Has Units: kg N/Year
IF THEN ELSE ( Time
        - INTEGER ( Time )
        > ( 0.33)
        :AND: Time
            - INTEGER ( Time )
            <= ( 0.833) ,
    ( ( total non open area[watershed]
        * 0.409679
        + impervious area[watershed]
            * 7.37422)
        * adjusted relative precipitation
            ^ elasticity of surface water runoff to precipitation )
        * 1.27,
    ( ( total non open area[watershed]
        * 0.409679
        + impervious area[watershed]
            * 7.37422)
        * adjusted relative precipitation
            ^ elasticity of surface water runoff to precipitation )
        * 0.73)
    * runoff loadings adjustment[watershed]
Has Units: acre

**********************************************
Error in units for the following equation:
non open space loadings Baseline[watershed]  =
```

```
    IF THEN ELSE ( Time
        - INTEGER ( Time )
        > ( 0.33)
        :AND: Time
            - INTEGER ( Time )
            <= ( 0.833) ,
      ( ( total non open area[watershed]
        * 0.409679
        + total impervious area Baseline[watershed]
            * 7.37422)
        * adjusted relative precipitation
            ^ elasticity of surface water runoff to precipitation
            )
        * 1.27,
      ( ( total non open area[watershed]
        * 0.409679
        + impervious area[watershed]
            * 7.37422)
        * adjusted relative precipitation
            ^ elasticity of surface water runoff to precipitation
            )
        * 0.73)
      * runoff loadings adjustment[watershed]
non open space loadings Baseline  --> kg N/Year
Time  --> Year
total non open area  --> acre
total impervious area Baseline  --> acre
adjusted relative precipitation  --> dmnl
elasticity of surface water runoff to precipitation  --> dmnl
impervious area  --> acre
runoff loadings adjustment  --> dmnl

Analysis of units error:
Right hand and left hand units do not match
non open space loadings Baseline[watershed]
Has Units: kg N/Year
IF THEN ELSE ( Time
    - INTEGER ( Time )
    > ( 0.33)
    :AND: Time
        - INTEGER ( Time )
        <= ( 0.833) ,
  ( ( total non open area[watershed]
    * 0.409679
```

```
        + total impervious area Baseline[watershed]
            * 7.37422)
        * adjusted relative precipitation
            ^ elasticity of surface water runoff to precipitation )
        * 1.27,
    ( ( total non open area[watershed]
        * 0.409679
        + impervious area[watershed]
            * 7.37422)
        * adjusted relative precipitation
            ^ elasticity of surface water runoff to precipitation )
        * 0.73)
    * runoff loadings adjustment[watershed]
Has Units: acre

*********************************************
Error in units for the following equation:
Summer chlorophyll A concentration by box[Boxes]  =
      max ( 0,
          57.5
              * ( ( N concentration by box[Boxes] )
                  ^ 2.09) )
Summer chlorophyll A concentration by box  --> ug/l
N concentration by box  --> g/m3

Analysis of units error:
Units for ^ with noninteger exponent (or > 9) must be dimensionless
( N concentration by box[Boxes] )
Has Units: g/m3

*********************************************
Error in units for the following equation:
Summer water turbidity secchi depth by box[Boxes]  =
      IF THEN ELSE ( Summer chlorophyll A concentration by box[Boxes
          ]
              > 39,
          0.5,
          2.83
              - 0.09
                  * ( Summer chlorophyll A concentration by box[Boxes
                  ] )
              + 0.000776
                  * ( Summer chlorophyll A concentration by box[Boxes
                  ] )
```

^ 2)
Summer water turbidity secchi depth by box --> meters
Summer chlorophyll A concentration by box --> ug/l

Analysis of units error:
Units mismatch
2.83
- 0.09
* (Summer chlorophyll A concentration by box[Boxes])
Has Units: ug/l
0.000776
* (Summer chlorophyll A concentration by box[Boxes])
^ 2
Has Units: ug*ug/(l*l)

****
Error in units for the following equation:
total surface water runoff loadings providence =
```
      IF THEN ELSE ( Time
              - INTEGER ( Time )
              > ( 0.33)
              :AND: Time
                  - INTEGER ( Time )
                  <= ( 0.833) ,
          ( total area providence
              * 0.409679
              + ( impervious area providence
                  * 7.37422
                  * 0.9)
                  * adjusted relative precipitation
                      ^ elasticity of surface water runoff to precipitation
                      )
              * 1.27,
          ( total area providence
              * 0.409679
              + ( impervious area providence
                  * 7.37422
                  * 0.9)
                  * adjusted relative precipitation
                      ^ elasticity of surface water runoff to precipitation
                      )
              * 0.73)
```
total surface water runoff loadings providence --> kg N/Year
Time --> Year

total area providence --> acre
impervious area providence --> acre
adjusted relative precipitation --> dmnl
elasticity of surface water runoff to precipitation --> dmnl

Analysis of units error:
Right hand and left hand units do not match
total surface water runoff loadings providence
Has Units: kg N/Year
IF THEN ELSE (Time
- INTEGER (Time)
> (0.33)
:AND: Time
- INTEGER (Time)
<= (0.833) ,
(total area providence
* 0.409679
+ (impervious area providence
* 7.37422
* 0.9)
* adjusted relative precipitation
^ elasticity of surface water runoff to precipitation
)
* 1.27,
(total area providence
* 0.409679
+ (impervious area providence
* 7.37422
* 0.9)
* adjusted relative precipitation
^ elasticity of surface water runoff to precipitation
)
* 0.73)
Has Units: acre

****
Error in units for the following equation:
total surface water runoff loadings taunton =
IF THEN ELSE (Time
- INTEGER (Time)
> (0.33)
:AND: Time
- INTEGER (Time)
<= (0.833) ,

```
          ( total area taunton
              * 0.409679
              + ( impervious area taunton
                  * 7.37422
                  * 0.9)
                  * adjusted relative precipitation
                      ^ elasticity of surface water runoff to precipitation
                      )
              * 1.27,
          ( total area taunton
              * 0.409679
              + ( impervious area taunton
                  * 7.37422
                  * 0.9)
                  * adjusted relative precipitation
                      ^ elasticity of surface water runoff to precipitation
                      )
              * 0.73)
total surface water runoff loadings taunton  --> kg N/Year
Time  --> Year
total area taunton  --> acre
impervious area taunton  --> acre
adjusted relative precipitation  --> dmnl
elasticity of surface water runoff to precipitation  --> dmnl

Analysis of units error:
Right hand and left hand units do not match
total surface water runoff loadings taunton
Has Units: kg N/Year
IF THEN ELSE ( Time
        - INTEGER ( Time )
        > ( 0.33)
        :AND: Time
            - INTEGER ( Time )
            <= ( 0.833) ,
    ( total area taunton
        * 0.409679
        + ( impervious area taunton
            * 7.37422
            * 0.9)
            * adjusted relative precipitation
                ^ elasticity of surface water runoff to precipitation
                )
        * 1.27,
```

```
  ( total area taunton
      * 0.409679
      + ( impervious area taunton
          * 7.37422
          * 0.9)
          * adjusted relative precipitation
              ^ elasticity of surface water runoff to precipitation
              )
      * 0.73)
Has Units: acre

********************************************
Error in units for the following equation:
water turbidity secchi depth[Boxes]  =
      IF THEN ELSE ( Annual chlorophyll A concentration by box[Boxes
          ]
              > 39,
          0.5,
          2.83
              - 0.09
                  * ( Annual chlorophyll A concentration by box[Boxes
                  ] )
              + 0.000776
                  * ( Annual chlorophyll A concentration by box[Boxes
                  ] )
                      ^ 2)
water turbidity secchi depth  --> meters
Annual chlorophyll A concentration by box  --> ug/l

Analysis of units error:
Units mismatch
2.83
    - 0.09
        * ( Annual chlorophyll A concentration by box[Boxes] )
Has Units: ug/l
0.000776
    * ( Annual chlorophyll A concentration by box[Boxes] )
        ^ 2
Has Units: ug*ug/(l*l)
```

APPENDIX B. SUMMARY OF STAKEHOLDER OUTREACH MEETINGS

JULY 27, 2011 STAKEHOLDER BRIEFING
MEETING NOTES

- Model looks at the length and breadth of the issue, not at whether or not to implement certain policies
- It will draw on current models of the Bay
- It will consider the impacts of climate change
- Model could be useful in showing how actions will make a difference
- Model will be most useful if it is customizable
- Need to be expansive in defining and quantifying societal benefits because this is how public support is generated; externalities are important
- Human behavior/ price setting relationship is strong – link nitrogen reduction to that, e.g. full cost accounting
- Who "owns" the model? Statewide planning agencies would like to use the model—they need information on land use as it relates to nitrogen
- Have a decision science expert involved upfront
- Model is focusing on nitrogen for now but can get more detailed.
- There is a regulatory requirement—the Clean Water Act (CWA)—and more needs to be done to meet it. Can EPA support this holistic model without downplaying the CWA?
- We're looking at a paradigm shift, and this systems model will help with that
- Determine baseline inputs—will the model set goals or help implement them. The goal isn't to set goals but help with the path forward
- Need to frame in terms of benefits which can be understood by public
- Will the model help with areas such as the effect of buffer setbacks on urban development, for example?
- Use of grey water/catchments, etc. The model could help drive the conversation towards the greater good
- Good to see holistic model and alternative approaches for sustainable futures. Look at historical trends
- Sensitivity analysis is necessary
- Will the model demonstrate the benefits of past actions?
- Model needs to be reasonably correct so it's actionable
- Need to know the objective: If X gives this, X minus would give that…
- People do value things, they just don't see the connections – can model help with that?
- Bring in experience from other parts of the country
- Quantify shellfish restoration impact if done in closed waters
- Model could be powerful advocacy tool to tap the RI public's commitment

- Does the model capture the ecosystem response? Yes, to degree we can
- Include all water use e.g. lawn watering
- RI has changed to LID stormwater management
- Be careful to not use model to shift cost burdens [among constituencies e.g. EJ]
- Work outside of just wastewater/water into alternative energy or others
- Other potential stakeholders:
    - Water Resources Board
    - RI municipalities
    - Faith based communities
    - Community of color
    - Urban league
    - GSO
    - Marine trades
    - Shellfish industry
    - NRCS
    - MA stakeholders
    - Chambers of Commerce
    - MA Municipal Association
    - Bob Durand model
    - Restore America's Estuary
    - Environmental engineers/ consultants

ATTENDEE LIST

NAME	ORGANIZATION
Alicia Good	Rhode Island Department of Environmental Management (RIDEM)
Ames Colt, PhD	Rhode Island Department of Environmental Management (RIDEM)
Angelo Liberti	Rhode Island Department of Environmental Management (RIDEM)
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Beth Ashman Collins	Community Economic Futures
Beth Collins	
Beth Termini	EPA Region 1
Bill Bnapolitand	Southeastern Regional Planning and Economic Development District
Bill Napolitano	Southeastern Regional Planning and Economic Development District
Chuck Noss	EPA HQ
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Richard Ribb	Narragansett Bay Estuary Program
Scott Wolf	Grow Smart Rhode Island
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Sue Kiernan	Rhode Island Department of Environmental Management (RIDEM)
Tim Gleason	EPA Region 1
Todd Blount	Blount Seafood
Tom Uva	Narragansett Bay Commission
Tony Simon	U.S. Senator Sheldon Whitehouse
Tricia Jedele	Rhode Island Conservation Law Foundation
Walt Galloway	EPA - Office of Research and Development (ORD)
Walter Berry	EPA - Office of Research and Development (ORD)
Warren Prell	Brown University
William Anderson	Rhode Island Resource Recovery Corporation

OCTOBER 12, 2011 STAKEHOLDER WORKSHOP
STAKEHOLDER FEEDBACK

1. PRESSURES

- Economic:
  - Misperception of conflict between economic development and environmental protection
  - Impact of additional cost of doing business
  - Increasing rates for WWTF upgrades adversely affects businesses and homeowners
  - Pressure to develop TMDLs and meet loading limits
  - How is decreasing nitrogen going to affect the fisherman's catch?
  - Help identify priority actions for ecosystem, economy, social systems
- Societal & Regulatory:
  - Public health impacts/benefits (e.g. fine particulate matter, ozone)
  - Need for better monitoring analysis and data sharing/management
  - No sustainable funding for stormwater management and retrofitting
  - How will this model be integrated with modeling done to develop TMDLs (on watershed and subwatershed scale)?
  - Linking background embedded in the model to specific policy questions and goals (capturing attention of policy makers)
- Environmental:
  - Goal of BRWCT is to implement a complete strategic planning cycle for Narragansett Bay watershed waters & associated human uses. This model could be an important tool for facilitating this interagency water strategic planning cycle
  - Water balance changes because of withdrawals, basin transfers, or increased/decreased infiltration
  - Value of non-harvested flora/fauna to ecosystem function
  - Interactions of intervention & GHG emissions

2. OPPORTUNITIES

- Policy & Process:
  - Rhode Island's smallness makes it a good pilot case
  - This information can help states and EPA achieve regional ecosystem-based management goals
  - Can this pilot spur greater collaboration and pooled, targeted resources?
  - It's not clear to me who will use this and why. I'm not a policy person or manager, so it's hard for me to understand who the final users are
  - An obstacle is how to educate the public across state boundaries and convey knowledge of watershed implications
  - Solicit stakeholder input from businesses/industry to help communicate the benefits of Bay and watershed improvements, and include their concerns (i.e. costs, potential adverse impacts on jobs in RI & MA)
  - Post the draft and let us play with it and get you some hands-on comments
  - Educate local and regional policy makers
  - Helps make the case for encouraging low impact development implementation
  - The model will be a useful policy tool. Question is how do we make it a powerful marketing tool?
  - Need to develop state and public interest group buy-in to a long-term process. Among other needs is a commitment by federal agencies to support and fund model refinement. Also need realistic exercises to tap legislative, executive, public interest

- Technical Content:
    - Add intervention for fertilizer use (negotiation)
    - Anticipate increased demand for safe seafood (no mercury)
    - Use investments to create new products for expanded markets (ammonia for fertilizer)
    - Account for multiple benefits of intervention. For example low impact development (LID) will address other pollutants, mitigate flood impacts and improve base flows in comparison to conventional storm water management
    - How can this model be used to spur (or account for) economic growth via nitrogen removal technologies. For example – use treatment technologies with useful by products (ammonia, methane, etc.)
    - Mariculture/Aquaculture: develop fertilizer business to remove sea lettuce/other seaweeds, compost, and sell them. The seaweeds will remove the nitrogen. Slower reinsertion into system (organic nitrogen) as you use (as in slow release nitrogen)
    - Train and certify local workforce (unskilled labor) in LID and green infrastructure at community colleges or university extension programs – also train this group in maintenance and monitoring of septic systems

3. CONFLICTS/CONSTRAINTS

- Economic:
    - Is the cost of doing business integrated into GDP outputs?
    - Cost of treatment actions and effect on economy (cost of doing business, taxes, user fees)
    - Credibility of model depends on confidence in the variables and formulations; model needs a lot more vetting and transparency of assumptions

- Societal:
    - Court cases, conflict, legal definitions and establishing nutrient limits hinders open discussion
    - Instituting change in development and redevelopment practices (turning the ship around)
    - Lack of watershed-based limits for nitrogen
    - Little incentives for multi-state coordination of policy and information
    - Funding and budgets at state & federal level
    - Money to implement upgrades
    - State agencies in RI and MA are overwhelmed with core regulatory tasks for which resources are already lacking. States and federal governments have to figure out how to fund the development and utilization of these emerging decision support tools.
    - Overlapping authorities and turf issues impede progress
    - Impact of politics on action
    - Difficulty communicating to public the benefits of pollution control vs. costs
- Environmental
    - Incorporating lag time in environmental results (e.g. nitrogen release from sediment)
    - Can past landings of fish and shellfish tell us if we are going to decrease nitrogen too much – i.e., get to loadings that are too low to sustain fisheries? Look at past nitrogen loadings vs. fish & shellfish landings
    - Aquaculture projects in Upper Bay could reduce nitrogen load. DEM/FDA regulations prohibit these projects in Upper Bay/closed waters
    - Different limiting nutrient (phosphorus vs. nitrogen) in different parts of the watershed (riverine vs. estuarine)

4. INFORMATION NEEDS/GAPS

- Economic:
  - Do costs of interventions also increase GDP? Or is GDP output of the model a net change?
  - Blackstone river coalition volunteer water quality monitoring data
  - Cost estimates and resulting benefits must be solid for the model to be respected
  - What is the rate and transport of nitrogen
  - Can we capture the marginal impact of Bay water quality on other industries (marine transportation, marine trades, marine technologies, waterfront amenities)? – see Ninigret Partners' Bay Economic Indicators Study
  - Need more fine-grained economic data
  - Better monitoring and assessment needed
  - Need to identify and prioritize stormwater sources/contributions watershed-wide
  - Costs/benefits of renewable energy
  - Need a table of sensitivity analyses on inputs to model (i.e., if you are off by 2 percent on the economic benefit a specific change in a parameter – what happens? i.e., what are the key driving factors for economics? environment?)
- Societal:
  - Engage municipal stakeholders
  - Include component for LID retrofits in existing development
  - Decision science
- Environmental:
  - Add the positive or negative impacts of eelgrass on recreational and commercial shellfishing (e.g., scallops) and fishing
  - Need to address phosphorus as well, for freshwater
  - Include the historical perspective of physical & biological changes observed in past 100 years
  - Impacts of change on Ctenophores –> increased predation on larval fish –> fish losses
  - Groundwater should be included, especially relative to septic systems
  - Nitrogen loading question: How much nitrogen comes from ISDSs – groundwater to Greenwich Bay (due to sandy soil, groundwater is likely significant here compared to other areas of Bay)? Source whole upper end of West Passage nitrogen here
  - Circulation patterns are a critical cause of hypoxia in Upper Bay. Narragansett Bay Commission's hydrologic model and CHRP model should be used as inputs to this model

5. DESIRED OUTCOMES

- Economic:
  - Perform technical analysis to determine most cost-effective solutions to achieve goals (i.e., nitrogen reduction)
  - Better general understanding of trade-offs involved
  - Identify areas/needs that call out for innovation (energy, collaborative mechanisms, funding mechanisms, etc.)
- Societal:
  - Educational targets re: ecology/economy
  - Develop a view of costs, benefits and efficiencies of LID – BMPs
  - Cost to WWTF rate payers for each facility upgrade and associated water quality improvement expected

- Sustainable solutions to improved dissolved oxygen levels in Upper Bay

- Environmental:
  - Healthy ecological function, normal assemblage and distribution of native plant & animal species
  - Minimize fish and shellfish die-offs
  - Minimum dissolved oxygen levels above 4 mg/L
  - Model to incorporate impacts of additional phosphorus removal levels
  - Build public support for greening urban areas
  - Monitoring to allow adaptation
  - Help calculate value of actions and justify costs

6. OTHER

- Scott Nixon, Candice Oviatt, and Chris Kincaid should be on stakeholder list
- Should have greater input from industrial stakeholders (i.e., manufacturing, fishing business, etc.)
- Be sure interested parties can see the background equations
- Who are the intended users? Would be good to start with problems/needs assessment with user input? What are anticipated uses/benefits of model?
- Social justice is not well represented
- Add the RI marine trades to the stakeholder list
- New research conducted shows greenhouse gas benefits of nutrient reductions at WWTFs even when considering energy impacts
- Need to see details on all the different model assumptions ASAP to give additional input. Sensitivity analysis results would help direct priorities for additional research and development.
- Provide a list of all nitrogen sources currently in the model.
- Need to build in factors for how sub-basin interventions impact the areas of the Bay with nutrient related impairments.
- Model should account for reduction in nitrogen that will result when current cesspools/septic systems are connected to sewers.
- Model should account for all planned WWTF nitrogen reductions (e.g., Bridgewater, MA etc., North Attleboro, Attleboro, Northbridge)
- Trading – a student at Brown developed website and thesis on this topic
- UBWPAD – wet weather facility is on-line
- Why were ISDSs included in stormwater runoff not groundwater?
- Mark Brush developing model on aquaculture intervention
- Look at INI model (Integrated Nitrogen Initiative?)

ATTENDEE LIST

NAME	ORGANIZATION
STAKEHOLDERS	
Beth Ashman	Community Economic Futures
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Tammy Gilpatrick	Blackstone River Coalition

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Patrick Hanner	City of East Providence
Sue Kiernan	RI Department of Environmental Management
Nancy Langrall	Senator Jack Reed's Office
Angelo Liberti	RI Department of Environmental Management
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Marisa Mazzotta	Environmental Economist
Jared Rhodes	RI Division of Planning
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Joe Rudek	Environmental Defense Fund
Michael Sparks	Blackstone River Coalition
John Torgan	Save the Bay
Tom Uva	Narragasett Bay Commission
Mike Walker	RI Economic Development Corporation
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